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Updating Bulldozer Fireline Production Rates

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RESEARCH SUMMARY

Bulldozers are an effective but expensive machine for building fireline; therefore, it is important for firefighters to have some means of estimating the rates at which various dozers can build fireline in different kinds of cover and terrain. The handbooks and reports currently available are based on studies done in the 1950's and early 1960's, and the fireline construction rates offered are outdated. The models listed in the publications have been replaced by improved models or entirely new models with higher production rates.

The goal of this study was to develop production rates for bulldozers manufactured since 1975 and to revise the production rates for older dozers manufactured from 1965 to 1975. Because of budgetary limitations, it was not possible to duplicate past field studies. The authors therefore utilized production indexes that manufacturers had devised to indicate comparative earth-moving capabilities of various models. The indexes were used to adjust old production rates to fit more modern bulldozers. Results are displayed in tables and production curves by dozer size, fuels, and slopes. Changes in rates of fireline construction range from insignificant to 20 percent improvement, depending on site factors.

CONTENTS

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INTRODUCTION

Since the early 1930's bulldozers have been used to construct firelines and perform other tasks in the control of wildland and prescribed fires (Pyne 1982). Dozers are especially valuable in situations where heavy vegetation, such as brush and logging slash, must be removed in order to establish a fireline to mineral soil. Although the use of bulldozers has been curtailed in some fragile ecosystems, the machines will continue to be a major tool in fireline construction.

Wildland fire managers need to know the rates of speed at which bulldozers can be expected to construct firelines in different situations of vegetation and slope. On a going fire, knowledge of bulldozer capabilities enables the fire boss and his assistants to determine the sizes and numbers of bulldozers needed to help produce the required length and width of fireline within a specified time. Planners need to know the production rates of bulldozers in order to meet the long-range objectives of fire management and land management. Planning models for the Forest Service's fire economics analysis (USDA Forest Service 1980) call for inputs of the production rates of different fireline-construction units, including bulldozers.

To facilitate short-term and long-range planning, fireline production rates for single bulldozers have been published in various fireline handbooks (British Columbia Forest Service 1976; USDA Forest Service 1971; National Wildfire Coordinating Group 1980). Because most of these rates are based upon studies made some 15 to 30 years ago, they primarily report the capabilities of older machines. They do not represent the capabilities of more recent models of bulldozers, which have been improved by new engines, transmissions, lubrication systems, hydraulic controls, and other features. The objective of this study, therefore, was to update the published rates of fireline construction for bulldozers manufactured since 1975. A secondary objective was to provide adjusted rates for bulldozers manufactured from 1965 to 1975; these rates are shown in appendix A. The study did not include production rates for tractor-drawn plows (Mobley and others 1979).

Past field studies of the fireline production rates of bulldozers were very costly and time-consuming (California Division of Forestry 1967; Steele 1961; USDA Forest Service 1948). Because of current budgetary limitations, however, land management agencies and protection agencies were unable to duplicate past field studies. Consequently, the authors sought a relatively inexpensive and yet reliable means of updating published production rates.

One such solution was found through correspondence with several manufacturers of bulldozers (Caterpillar Tractor Co.; International-Hough, Dresser Industries; John Deere Industrial Co.). One manufacturer had developed production indexes for each model of bulldozer built since 1947, based on general earthmoving capability. The production indexes seemed promising for adjusting fireline production rates established during two earlier, well-documented studies of bulldozer use for constructing firelines (California Division of Forestry 1967; Steele 1961).

This report describes how rates were updated and presents the new production rates in both tables and graphs. Although we believe that the adjusted rates are reasonably accurate, they must be validated in brief field tests.

SIZES OF BULLDOZERS USED IN FIRELINE CONSTRUCTION

In presenting rates of fireline production, it is desirable to classify bulldozers by size. Because there are no interagency standards, the authors have arbitrarily classified bulldozers into three general sizes:

Size class	Weight	Net horse power	Blade width	Track gage	Track area on ground
	Tons		*Ft*	*Ft*	*Inch*^{2}
Small	5-10	55-95	8-9	5±	1,500-2,900
Medium	11-20	100-195	10-12	6±	3,000-4,200
Large	21-40	200-350	13-16	7±	4,300-6,300

Because of the variation in the features of different makes of bulldozers, and because there are so many bulldozers in each size class, the specifications in the above table are broad and imprecise. The classes correspond to those of the National Interagency Incident Management System (NIIMS) as follows:

Study class	NIIMS class
Small	3
Medium	2
Large	1

Tables of detailed characteristics of specific makes and models of bulldozers, by size classes, are available from the authors. Also available from the authors is a partial inventory of bulldozers owned or controlled by State and Federal fire protection agencies in the United States as of early 1983. It includes information obtained from 23 States, all regions but one of the Forest Service, and four State divisions of the Bureau of Land Management.

PAST STUDIES OF BULLDOZER FIRELINE PRODUCTION RATES

There have been several studies of the rates at which bulldozers can build fireline. In 1969, Storey summarized bulldozer production rates that had been published in various fireline handbooks (Storey 1969). He found considerable variation in rates among the handbooks for the same size classes of bulldozers. Because original data were lacking and descriptions of conditions were poor, he was unable to explain the variation in terms of differences in vegetation, soil, slope, and other pertinent factors. His table summarizing the published rates showed differences because of bulldozer sizes and resistance-to-control classes for vegetation, but gave no breakdown of upslope and downslope rates. Storey concluded that most bulldozer fireline production rates being used at that time were suspect, inaccurate, limited in their usefulness, and badly outdated. He noted few exceptions to his general conclusions.

Forest Service Study

One of the earlier studies was made by the Forest Service's Arcadia Equipment Development Center (now San Dimas Equipment Development Center) in November and December 1946 (USDA Forest Service 1948). The primary objective of the study was to compare the performances of Caterpillar D6 and D7 bulldozers equipped with hydraulic angle dozers.

The principal concern was the rate of single-pass fireline construction in medium and heavy brush and on a variety of slopes. ("Single pass" is defined as a single bulldozer constructing a fireline to mineral soil, one-blade wide. The bulldozer may have to back up occasionally and veer to one side or the other to clear its blade of debris and earth.)

The study was conducted on the Angeles National Forest in southern California under conditions almost ideal for bulldozer operation. The ambient temperature, although not reported, was probably about 50° F (10° C) during the months of November and December. Soil that had been thoroughly moistened by fall rains provided maximum traction.

Among the results of the study were these:

1. The D6 compared favorably with the D7 for fireline construction in brush.
2. The D7 produced about 20 percent more length of single-pass fireline under all conditions of slope and vegetation.
3. Downslope production of fireline was greater than upslope production by an average of 115 percent at 20 percent slope, and 500 percent at 40 percent slope.
4. Maximum gradability with blade raised in light brush was about 73 percent for the D7 and 65 percent for the D6. In heavy brush the figures decreased to about 50 percent and 46 percent, respectively.
5. Angling the blade was always more effective in line construction than using a straight blade.

The fireline production rates of these tests are shown graphically in figure 1.

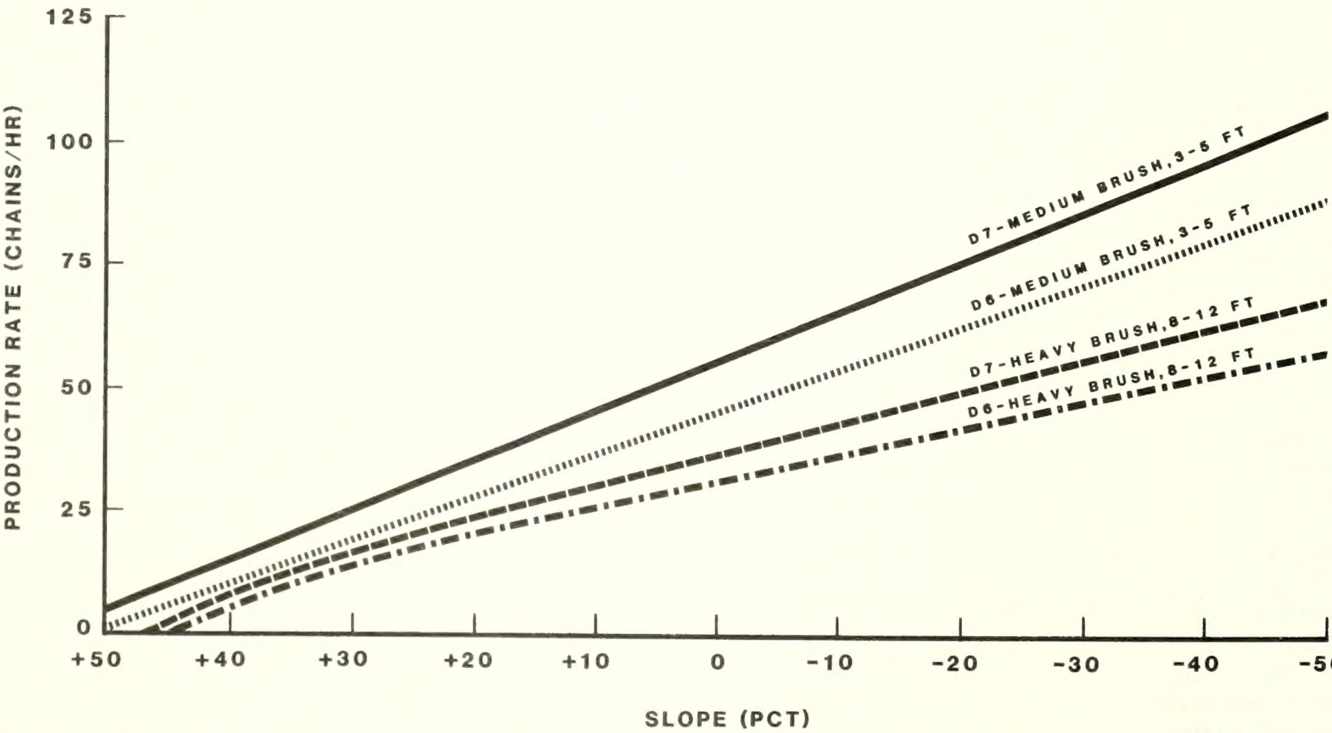

Figure 1.—Bulldozer fireline production rates (single pass) from 1946 study by Forest Service.

Robert W. Steele Study

During the period of 1954-59, Steele collected data on bulldozer fireline production rates during going fires and also on a few practice runs in timber types in Montana and Idaho (Steele 1961). Because most of the data came from actual wildfires, a wide range of makes and sizes of bulldozers was represented. Bulldozers observed in the study had cable-actuated blades that had to be manually changed from straight to angle position. All transmissions were manually shifted.

Steele classified his data using the following criteria:

a. Size of bulldozer (large, medium, small—using essentially the same size criteria as in this report).

b. Resistance to control of vegetation (extreme, high, medium, low).

c. Slope (to 30 percent upslope and 40 percent downslope).

d. Soil ("easy" and "rocky").

To account for operator skill, Steele included the work of only experienced, full-time operators.

Among the results of Steele's study were the following:

1. Vegetation affected production rates primarily in the amount and size of material that had to be cut or uprooted and in the rapidity with which it built up on the blade.

2. Slope was critical from the standpoint of being upslope or downslope; Steele found an optimum slope at minus 10 to 15 percent. Flatter slopes or upslopes produced slower rates, as did the steepest downslopes. On the latter Steele found that rates were reduced because of the increasing difficulty of backing bulldozers to clear blades of debris.

3. At 30 percent grade in vegetation with high resistance, Steele found that downslope rates were about 80 percent greater than upslope rates; for a 10 percent grade, the difference in production rates was about 33 percent.

4. Soil influenced production rates through differences in traction and through the need to move or to avoid large rocks.

The fireline production rates of Steele's study in "easy" soil are shown graphically in figures 2 through 4.

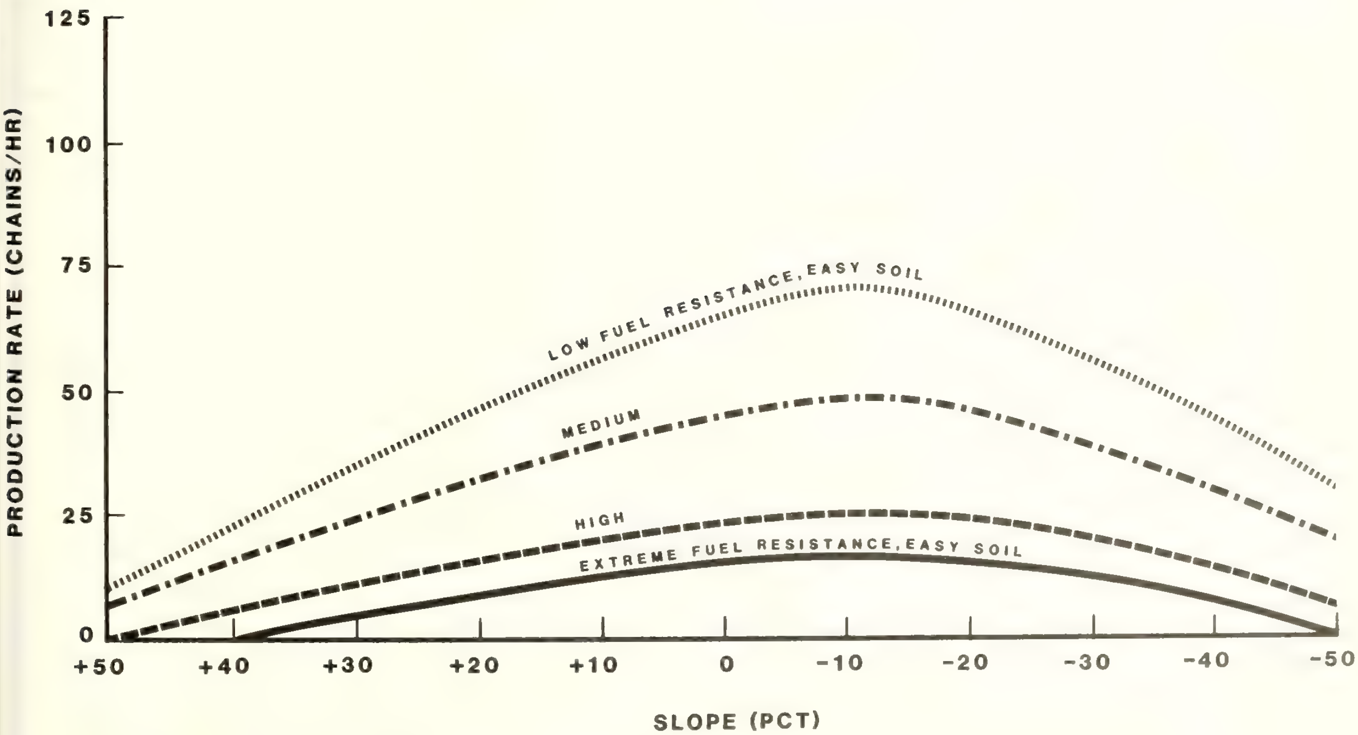

Figure 2.—Large bulldozer fireline production rates (single pass) from 1954-59 study by Robert W. Steele.

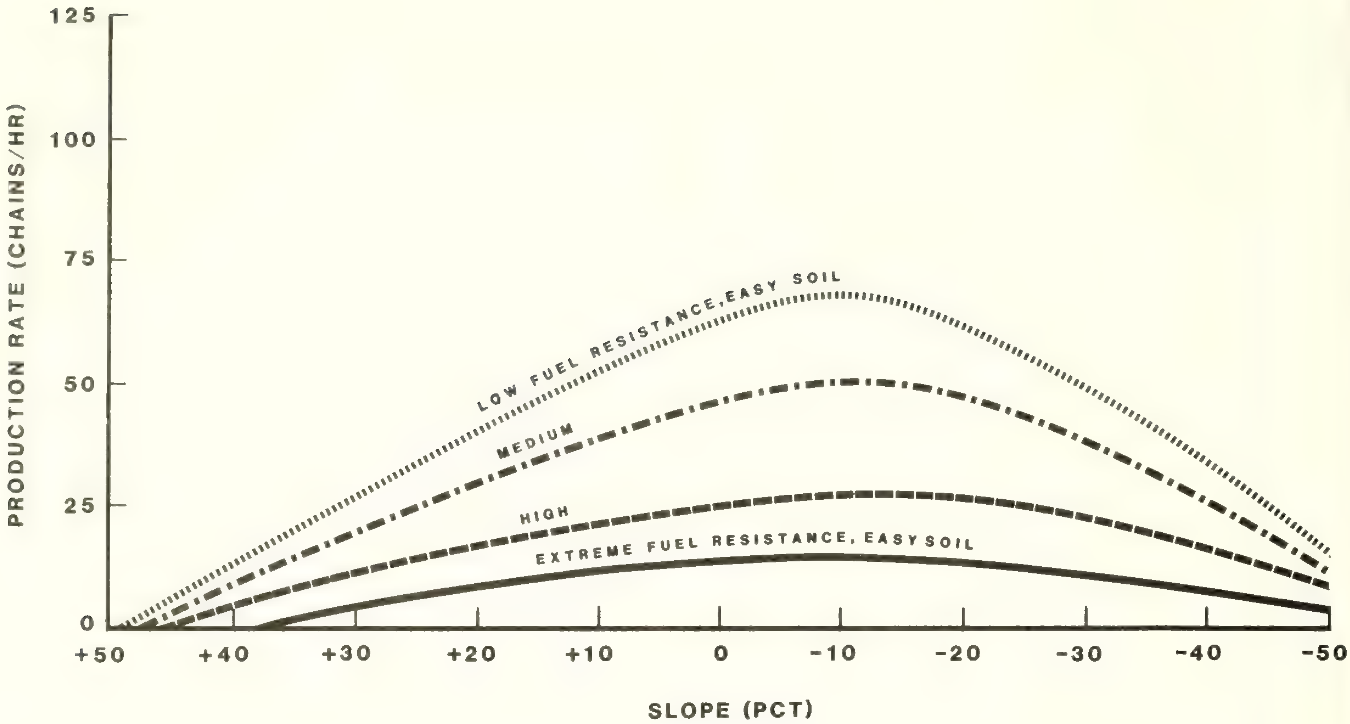

Figure 3.—Medium bulldozer fireline production rates (single pass) from 1954-59 study by Robert W. Steele.

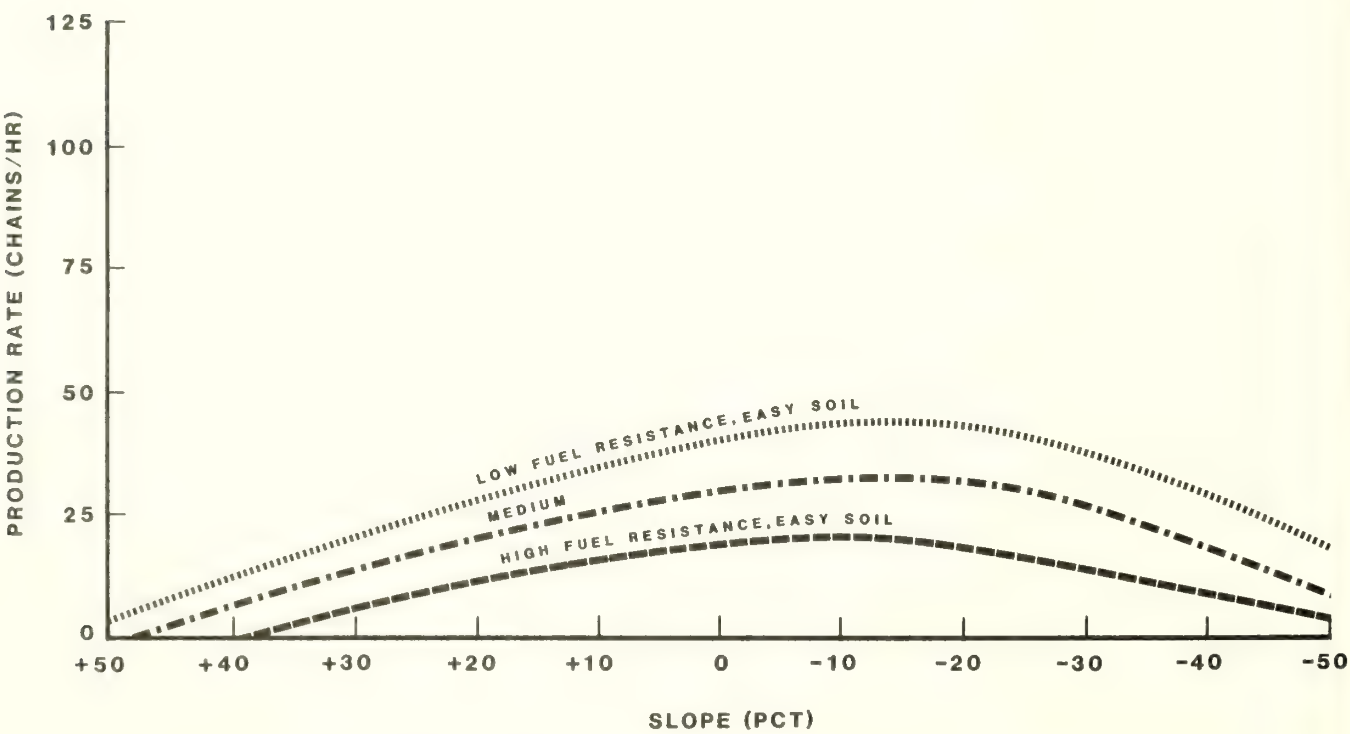

Figure 4.—Small bulldozer fireline production rates (single pass) from 1954-59 study by Robert W. Steele.

California Department of Forestry Studies

The California Department of Forestry (CDF) has conducted several studies of bulldozer fireline production rates: 1949 (medium-sized bulldozers), 1952 (small), 1955 (medium), 1956 (small), 1963 (medium), 1967 (small and medium), and 1975 (medium). The latter three studies used bulldozers with only power-shift transmissions and therefore began to account for the increased capabilities that came with more modern equipment.

The CDF's most extensive and carefully conducted study tested four makes of small bulldozers and three makes of medium bulldozers during a 5-week period in June and July 1967 (California Division of Forestry 1967). Ambient temperatures ranged from 78° to 106° F (26° - 41° C) in the afternoons, with most afternoons having temperatures in the mid- to high 90°'s. The high temperatures promoted overheating in two bulldozers, curtailing their use in the tests. The vegetation was mostly chaparral, with a few openings of grass. The chaparral was classed as low (up to about 3 feet [0.9 m] in height), medium (between 3 and about 8 feet [0.9 – 2.4 m]), and high (above 8 feet [2.4 m]). Line production was studied on slopes up to 50 percent, both upslope and downslope. Soil moisture, while not measured, was extremely low and representative of normal midsummer conditions in California. The surface soil was mostly shaley clay loam, from 3 to 24 inches (7.6 to 61 cm) thick and overlying a parent rock of fractured shale (personal correspondence, Hastings 1982). All bulldozers were fairly new and in good operating condition. Operators were selected from among the CDF's permanent employees, based upon their years of experience and demonstrated skills.

The study results included the following:

1. Downslope production of fireline was considerably greater than upslope; over all brush types, it averaged about 32 percent more at 10 percent slope, and about 140 percent at 30 percent slope.
2. While there was a gradual reduction in line production for steepening grades upslope, there was a gradual increase in line production for steepening grades downslope to the point where steepness caused the bulldozers to have difficulty in backing up for the purpose of clearing their blades and taking another run at cleaning the line.
3. Side slopes did not significantly affect upslope line production; downslope line production was reduced for medium-sized bulldozers for side slopes of 30 percent or more, but less so for the better balanced small-sized bulldozers.
4. Maximum gradability in light grass and favorable soil type averaged about 75 percent for medium bulldozers with raised blades in forward gear; maximum gradability was about 65 percent in reverse gear. The corresponding figures for small bulldozers averaged about 67 percent in forward gear and 56 percent in reverse.

The fireline production rates established in the 1967 study are shown in figures 5 and 6. The curves in these figures are averages from original data obtained for the four makes of small bulldozers and three makes of medium bulldozers.

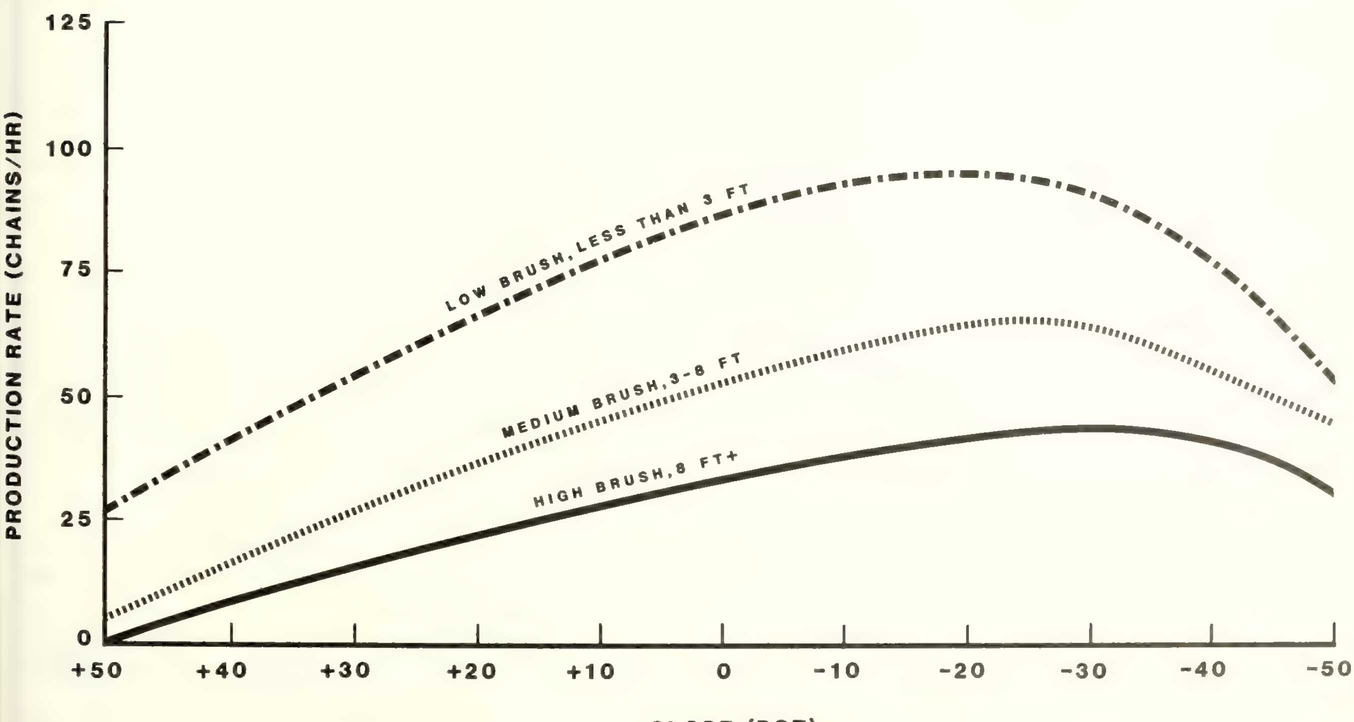

Figure 5.—Medium bulldozer fireline production rates (single pass) from 1967 study by California Department of Forestry.

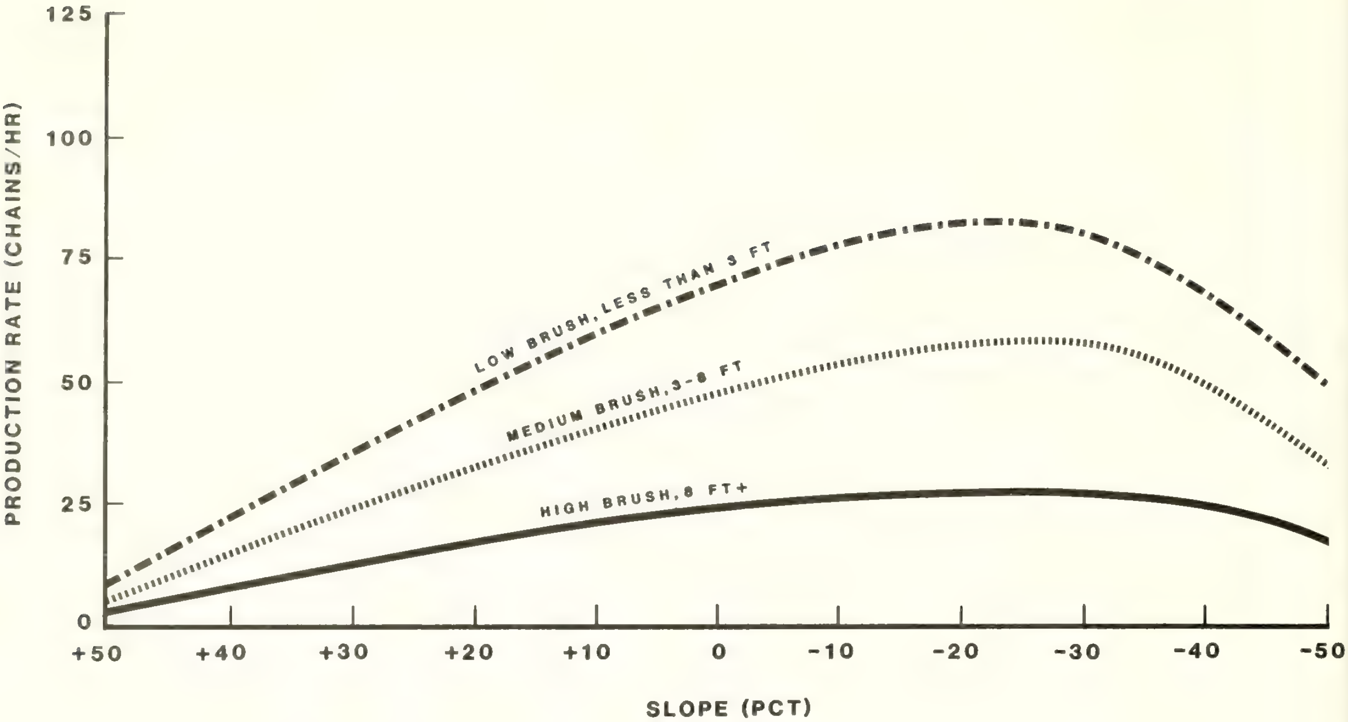

Figure 6.—Small bulldozer fireline production rates (single pass) from 1967 study by California Department of Forestry.

ANALYSIS OF PAST STUDIES

Unfortunately, original data for many past studies of bulldozer fireline production rates are lacking. Storey reported an inability to find such data for the production rates shown in various fireline handbooks and summarized in his report (Storey 1969). Even the rates in the most recent fireline handbook appear to be older ones that have been reworked on paper (National Wildfire Coordinating Group 1980).

To select a usable base of data for this study, therefore, there seemed to be no choice but to turn to those few published reports that presented observed production rates supported by well-documented methodology and environmental variables. Those reports were the three described above—the Forest Service's study of 1946, Steele's study of 1954-59, and the California Department of Forestry's study of 1967.

Because line production rates for bulldozers were displayed in different ways in each of the three reports, they had to be converted to a common graphic base for comparison in this report (figs. 1-6).

The results of the three published studies agreed in many respects, although there were some differences. The general agreements included the following important points:

1. The rate of upslope line production decreased gradually to the maximum working gradability of about 40 to 50 percent in heavy vegetation and to a slightly steeper grade in grass and other light vegetation.

2. The rate of downslope line production was considerably more than upslope for all grades of slope.

3. For Steele's and the CDF's studies, the rate of downslope line production increased to a grade of about 15 to 40 percent, depending on vegetation and soil, and then began to decrease because of the incremental difficulty of backing bulldozers to dump loads and make another forward run at cleaning the line.

4. The curves of line production in the Forest Service's 1946 study agreed closely with those of the CDF's 1967 study except for the tails of the downslope curves at 30 to 50 percent grade (figs. 7 and 8). This agreement existed despite the lapse of 21 years between the two studies and, consequently, despite an expected difference in bulldozer capability. The agreement in results, despite the time lapse, might be explained by the following reasons:

a. The November-December 1946 study was conducted under ideal conditions of thoroughly moistened soil and air temperatures that were typically low for the months; the June-July 1967 study was conducted under much more severe environmental conditions of dry soil and air temperatures ranging above 100° F (38° C).

b. The 1946 study was made with just two bulldozers from the same manufacturer; the curves shown for the 1967 study represented an average for several makes of bulldozers.

5. The maximum gradability for medium bulldozers was about the same in the Forest Service and CDF studies (about 70 percent). Steele did not specify maximum gradability in his study, although he used a slope of +30 percent as a "point of minimum speed" of upslope line production.

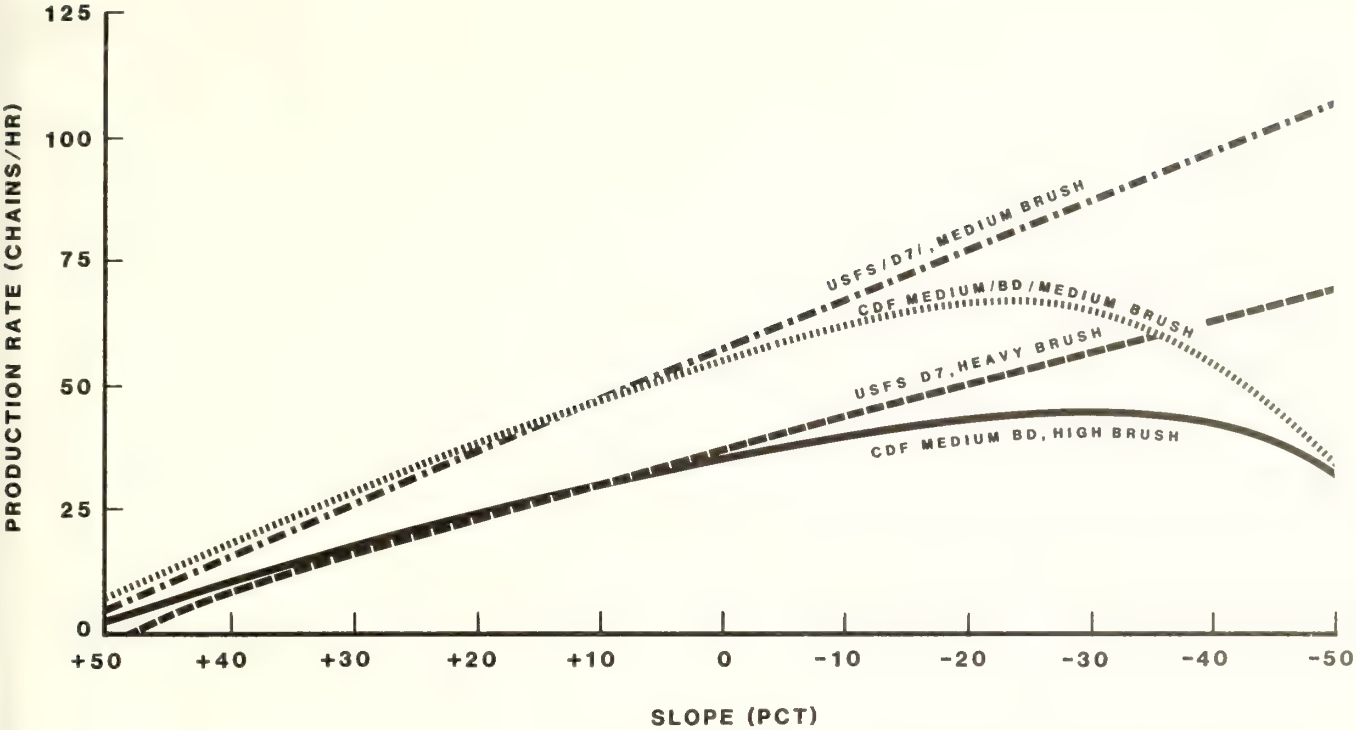

Figure 7.—Comparison of medium bulldozer fireline production rates from 1946 study by Forest Service and 1967 study by California Department of Forestry.

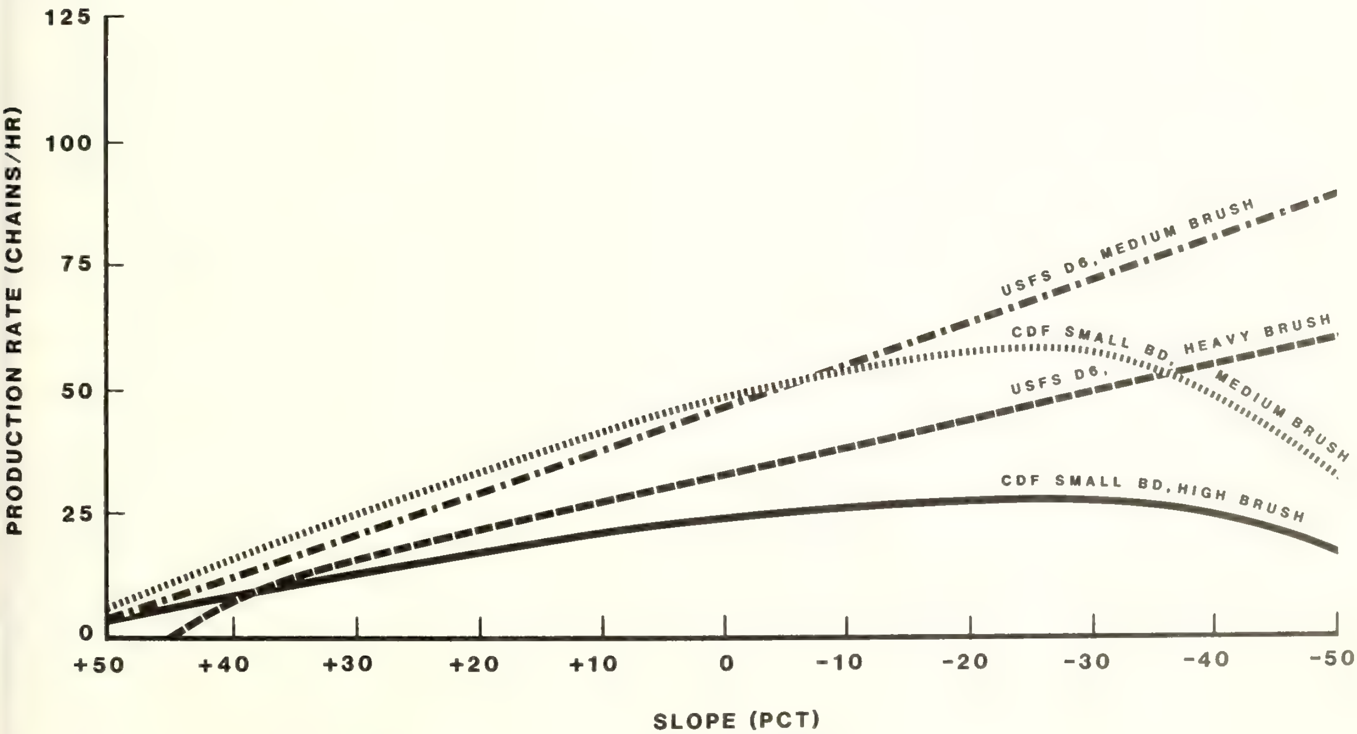

Figure 8.—Comparison of small bulldozer fireline production rates from 1946 study by Forest Service and 1967 study by California Department of Forestry.

Among the important differences in the results of the three studies were the following:

1. The Forest Service's production rates for downslopes continue to increase to a maximum workable grade of about 60 percent. Contrary to the results of Steele's and the CDF's studies, there was no decreasing tail in the production curve for the steeper slopes. The reason for the anomaly in the Forest Service's results could not be ascertained from the report.

2. The grade at which the maximum rate of line production occurred for downslopes was different for Steele's and the CDF's studies. For the former study, it occurred at 10 to 15 percent; for the latter, at 20 to 40 percent, depending on the size of bulldozer and the vegetative type. This difference might be attributed to the machines in Steele's study—older, less powerful models with manually operated transmissions and cable-activated blades. All in all, the older machines' lower capability also reduced the operators' confidence in their equipment.

3. Much of the vegetation in Steele's study was heavy timber or some variation (slash, downed logs, windfalls, closed stands of young growth, etc.). Vegetation in the Forest Service's and the CDF's studies was mostly chaparral, with some grass.

None of the three studies provided any significant data for two bulldozers working in tandem. Because no alternative sources of two-bulldozer rates of fireline production could be found, this study was confined to rates for single bulldozers constructing single-pass firelines.

SELECTION OF BASE RATES FOR FIRELINE PRODUCTION

Considering the available sources of bulldozer fireline production rates already discussed, it appeared that the base rates for this study should come from a combination of the CDF's 1967 study and Steele's study of 1954-59. Although the two studies had a few shortcomings, they did provide results that were realistic, defensible, usable, and feasible for updating. The Forest Service's 1946 study helped support the CDF's study, but could not be used because it was conducted under ideal postseason conditions and had an important and unexplained anomaly of no decrease in production rates for the steepest downslopes.

To be more useful in fire protection and fire management planning today, the production rates from the two selected studies had to be updated and rearranged. As a part of that updating process, separate rates needed to be established for the following variables:

1. Each of the 13 fire behavior fuel models (Anderson 1982).

2. Both upslope and downslope construction of fireline.

3. The first three slope classes of the National Fire-Danger Rating System (Deeming and others 1977): 0-25 percent, 26-40 percent, 41-55 percent.

4. Three size classes of bulldozers (small, medium, large).

Those four variables were the most important and practical to include in tables of bulldozer fireline production rates. Other conditions were held constant in this study and were generally consistent with Steele's and the CDF's studies:

a. Width of fireline. The rates are for single-pass lines: a single bulldozer constructing a fireline to mineral soil, one blade wide.

b. Line location. Assumed to be mostly indirect.

c. Operator qualifications. The best qualified based upon experience, knowledge, and demonstrated skill.

d. Equipment capability. Generally representative of bulldozers manufactured since 1975; in good maintenance and operating condition.

e. No lost time. Rates do not provide for rest stops, operator fatigue in extended attack situations beyond 6 to 8 hours, servicing of equipment, use of winches, or lost (unused) lines.

f. Fire conditions. Fire behavior assumed to be "average"; smoke does not obscure line construction.

g. Soil. Assumed to be fully dry and of a type that provides reasonably good traction.

h. Air temperature. Assumed to represent high summer temperatures ranging from 85° F (29° C) to 105° F (41° C).

i. Time of day. Assumed to be daylight hours.

If these constants differ from those in actual use, production rates shown in this study's tables and figures should be adjusted accordingly.

PROCEDURE FOR UPDATING BASE RATES

Current budgets for fire protection and fire management did not provide for extensive field studies for new models of bulldozers. Therefore adjusting the results of Steele's study of 1954-59 and the CDF's study of 1967 seemed to be the most practical alternative. That was done as follows:

1. Subjectively changing the shape of the curves from Steele's study to fit more closely the shape of the curves from the CDF's study.

2. Subjectively relating the various curves from the two studies to the 13 fire behavior fuel models.

3. Reading rates of line production from the curves for the midpoints of the three slope classes and tabulating them.

4. Adjusting the older production rates to account for the increased capability of newer models of bulldozers by using production indexes established by the manufacturers of bulldozers for other earth-moving applications.

5. Checking the logic and accuracy of the adjusted production rates by preparing new families of curves for each bulldozer size class, and making subjective changes where necessary.

6. Reading rates of line production from the new curves for the midpoints of the three slope classes and recording them in a new table; rearranging the updated fireline production rates in tables useful to planners of fire protection and fire management programs.

(A seventh step would be to verify the updated rates on a sample basis in an abbreviated field study some time in the future.)

Changing the Shape of Curves from Steele's Study

Because the older bulldozers observed in Steele's study had much less capability than newer machines, the production curves had to be adjusted upward at the two ends of maximum slope. A "zero" production rate at +30 percent or -40 percent slope, as shown in Steele's study, was not a reasonable base for calculating rates for newer bulldozers. Also, each curve for low fuel resistance needed to be raised to provide a more logical relationship within the overall family of curves. These adjustments were strictly subjective ("eyeballing") to make the curves from Steele's study resemble more closely those from the CDF's study of more modern bulldozers. The adjusted curves for Steele's study are shown with those of the CDF's study in figures 9 to 11.

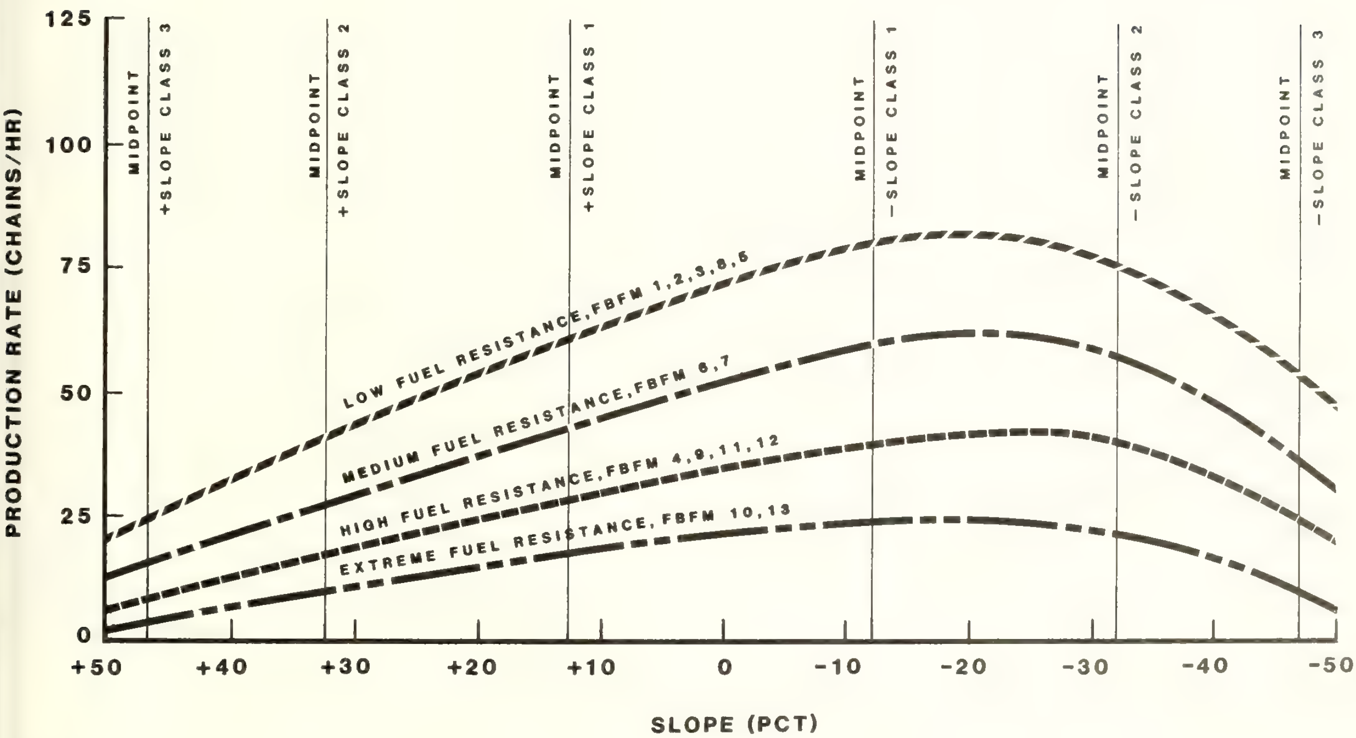

Figure 9.—Base rates for large bulldozer fireline production (single pass) from 1954-59 study by Robert W. Steele.

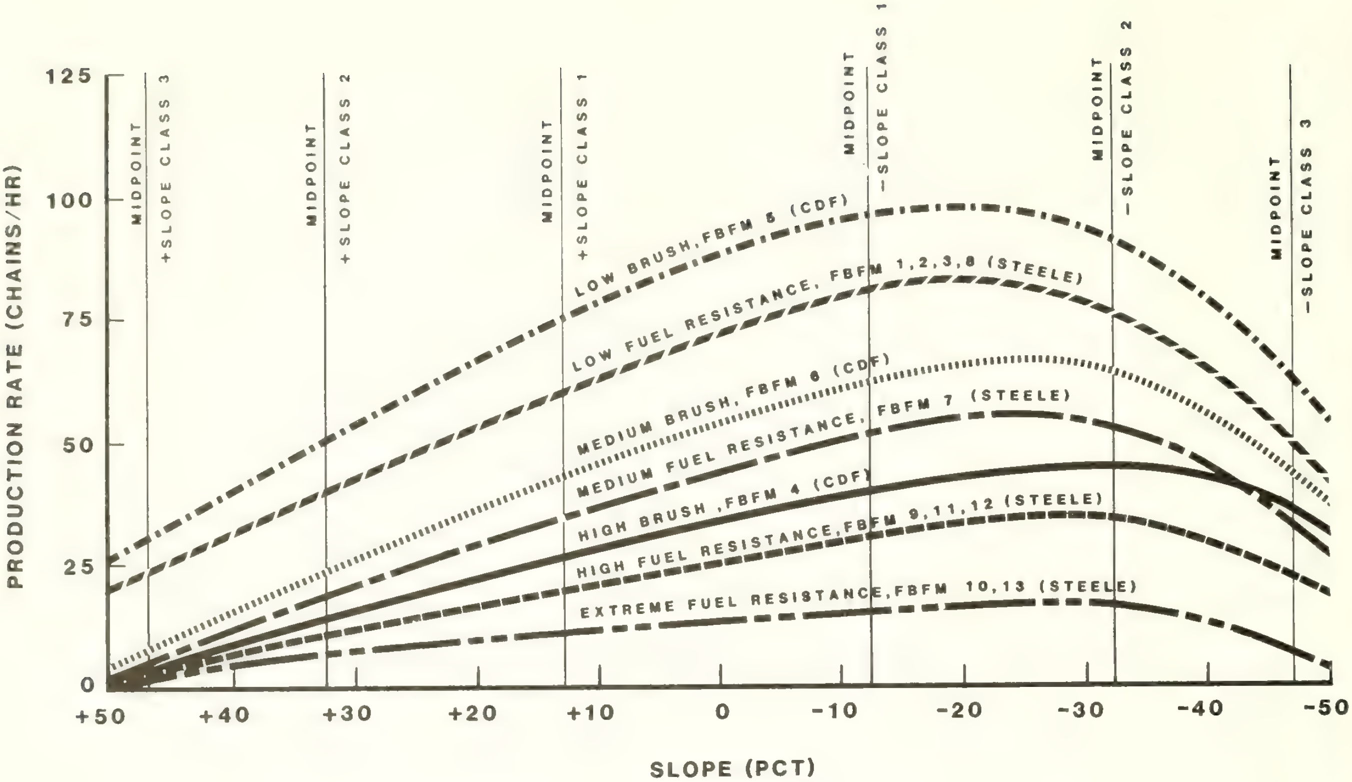

Figure 10.—Base rates for medium bulldozer fireline production (single pass) from 1954-59 study by Robert W. Steele, and 1967 study by California Department of Forestry.

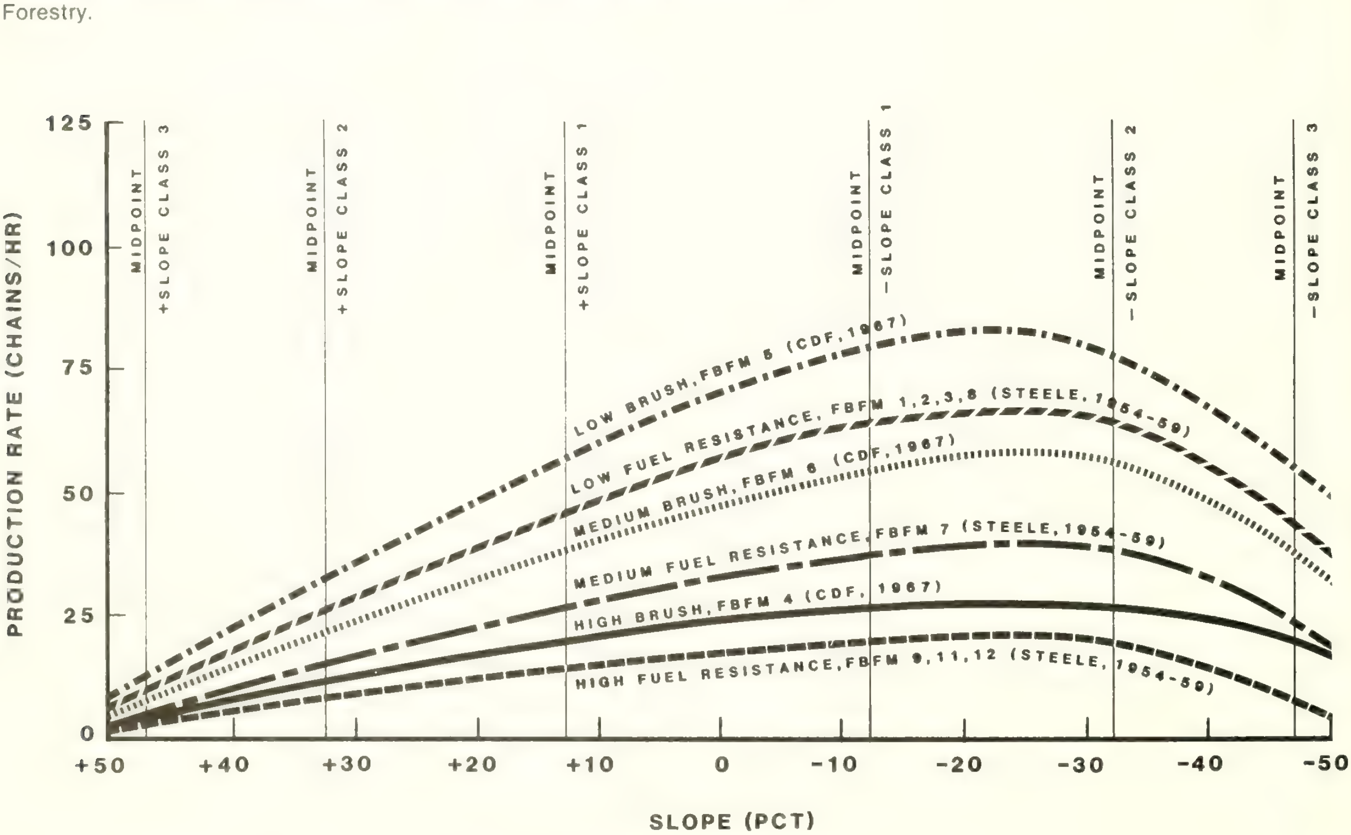

Figure 11.—Base rates for small bulldozer fireline production (single pass) from 1954-59 study by Robert W. Steele, and 1967 study by California Department of Forestry.

Relating the Curves to the 13 Fire Behavior Fuel Models

For fireline handbooks and tactical planning, it seemed most desirable to offer bulldozer fireline production rates for each of the 13 fire behavior fuel models. This breakdown would not fit some computerized models that utilize the fuel models of the National Fire-Danger Rating System (Deeming and others 1977). The 13 fire behavior fuel models have been correlated to the fuel models of the National Fire-Danger Rating System (Anderson 1982) and are presented in appendix B.

To establish production rates for the 13 fire behavior fuel models, it was necessary to compare descriptions of the fuel models to vegetation actually encountered and described in Steele's and the CDF's studies. That comparison was made possible by Anderson's (1982) publication, which described the 13 fire behavior fuel models in photographs and included a table of fuel volume by size classes.

Obviously, not all 13 fuel models were encountered in Steele's and the CDF's studies. Nevertheless, using the fuel model descriptions and the admonition to "regard vegetation as fire areas—as a fuel—and evaluate it in terms that relate to fire behavior" (Anderson 1974), it was possible to establish subjectively the tentative relationships shown in table 1. Admittedly, some of the tentative relationships may have to be changed, if indicated by future field testing.

In figure 11 note that there are no base rates for small bulldozers in fire behavior fuel models 10 and 13. Studies by Steele and the CDF indicated that small bulldozers are not effective in such heavy fuels and that production rates would be extremely low.

Tabulating Fireline Production Rates

The next step was to read the line production rates from figures 9 to 11 and record them in a table. Because the computerized planning models need fireline production rates for each slope class, the rates were read from the midpoints of those classes:

Slope class	Range of slope	Midpoint of class
	Percent	*Percent*
1	0-25	12.5
2	26-40	32.5
3	41-55	47.5

These rates were recorded in table 2 in the columns designated "Study."

With few exceptions, it is impractical to operate bulldozers on slopes beyond 55 percent (California Division of Forestry 1967). Steeper slopes can be effectively worked up to maximum gradability only if the vegetation is light and soil conditions are more favorable than those assumed for the tables of production rates in this study. If those conditions exist, then the rates shown in the tables can be adjusted appropriately.

Table 1.—Relationships between fire behavior fuel models and vegetation from the CDF's and Steele's studies

Fire behavior fuel model	General description	Curve from CDF's or Steele's study
1	Short grass	Steele—low fuel resistance
2	Grass understory in timber	Steele—low fuel resistance
3	Tall grass	Steele—low fuel resistance
4	Tall chaparral	CDF—high brush (for large bulldozers only, use Steele—high fuel resistance)
5	Short brush	CDF—low brush (for large bulldozers only, use Steele—low fuel resistance)
6	Dormant brush, hardwood slash	CDF—medium brush (for large bulldozers only, use Steele—medium fuel resistance)
7	Southern rough	Steele—medium fuel resistance
8	Litter in closed timber	Steele—low fuel resistance
9	Hardwood litter	Steele—high fuel resistance
10	Heavy litter in timber	Steele—extreme fuel resistance
11	Light logging slash	Steele—high fuel resistance
12	Medium logging slash	Steele—high fuel resistance
13	Heavy logging slash	Steele—extreme fuel resistance

Table 2.—Bulldozer fireline production rates obtained from past studies of bulldozers; adjusted to reflect capabilities of new models of bulldozers (rates shown are in chains-per-hour; taken from figures 9 to 11)

Vegetative type in study	Fire behavior fuel model	+ Slope class 1 Study	+ Slope class 1 New	+ Slope class 2 Study	+ Slope class 2 New	+ Slope class 3 Study	+ Slope class 3 New	- Slope class 1 Study	- Slope class 1 New	- Slope class 2 Study	- Slope class 2 New	- Slope class 3 Study	- Slope class 3 New
Small bulldozers													
CDF 1967 study - Test PI = 13 (D4D-PS); new PI = 14 (D4E-PS); PIΔ% = 7.7													
Low brush	5	57	61	32	34	12	13	81	87	79	85	56	60
Medium brush	6	38	41	22	24	7	8	55	59	58	62	39	42
High brush	4	20	22	11	12	3	3	27	29	28	30	20	22
Steele 1954-59 study - Test PI = 10 (D4-DD); new PI = 14 (D4E-PS); PIΔ% = 40.0													
Low fuel resistance	1,2,3,8	46	64	26	36	10	14	64	90	66	92	44	62
Medium fuel resistance	7	26	36	15	21	5	7	37	52	40	56	25	35
High fuel resistance	9,11,12	14	20	8	11	2	3	21	29	21	29	8	11
Medium bulldozers													
CDF 1967 study - Test PI = 18 (D6C-PS); new PI = 21 (D6D-PS); PIΔ% = 16.7													
Low brush	5	76	87	51	60	31	36	97	113	93	109	63	74
Medium brush	6	43	50	23	27	8	9	62	72	65	76	43	50
High brush	4	27	32	14	16	3	4	40	47	46	54	37	43
Steele 1954-59 study - Test PI = 14 (D6-DD)· new PI = 21 (D6D-PS); PIΔ% = 50.0													
Low fuel resistance	1,2,3,8	60	90	40	60	24	36	82	123	78	117	50	75
Medium fuel resistance	7	34	51	18	27	5	8	52	78	55	83	33	50
High fuel resistance	9,11,12	19	29	10	15	3	5	31	47	36	54	22	33
Extreme fuel resistance	10,13	11	17	7	11	2	3	15	23	17	26	7	11
Large bulldozers													
Steele 1954-59 study - Test PI = 19 (D7D-DD); new PI = 28 (D7G-PS); PIΔ% = 47.4													
Low fuel resistance	1,2,3,5,8	62	91	42	62	24	35	84	124	80	118	56	83
Medium fuel resistance	6,7	43	63	28	41	15	22	62	91	61	90	39	57
High fuel resistance	4,9,11,12	29	43	18	27	8	12	41	60	42	62	27	40
Extreme fuel resistance	10,13	18	27	10	15	3	4	26	38	23	34	11	16

Notes
"Study" rates of bulldozer production are taken from past studies indicated in the left column.
"New" rates of bulldozer production are the "study" rates adjusted by "Δ%".
"PI" = Production Index from table 3 for the appropriate size of bulldozer used in past studies and for new models of bulldozers.

Updating Fireline Production Rates

The fireline production rates established from the curves in figures 9 to 11 needed to be increased to account for the improved capability of newer models of bulldozers. This was done with data provided by three manufacturers of bulldozers. Although the data were derived from earth-moving tests other than building fireline, the authors assumed that it could be extrapolated to fireline construction.

The Caterpillar Tractor Co. supplied a table of productivity indexes for its bulldozers manufactured since 1947 (table 3). A letter from that company stated:

> The productivity indices shown are based on extensive studies in conventional dozing applications over the past thirty years. They should provide a realistic estimate of productivity increases in fire trail construction. Note, for example, today's D6D powershift is more productive than the popular 17A series D7 of 1955-1961. (Caterpillar Tractor Co. 1982)

As further examples, table 3 shows a production index (PI) of 14 for Caterpillar's new D4E-PS (in the small size class of bulldozers) in comparison to a PI=13 for the D4D-PS used in CDF's 1967 study. That represents an expected increase in productivity of 7.7 percent (14-13/13 = 0.077). Similarly, Caterpillar's D6D-PS (in the medium size class of bulldozers) has a PI=21, compared to a PI=18 for the D6C-PS used in CDF's 1967 study. This is an expected increase in productivity of 16.7 percent (21-18/18 = 0.167).

Table 3.—Productivity indexes for Caterpillar tractors

Model	Serial number	Years manufactured	Productivity index
D2-DD	4U	47-58	7
D3-PS	79U	72-79	11
D3B-PS	27Y	79-	12
D4-DD	6U	47-59	10
D4C-DD	39A	59-63	11
D4D-DD	78A	63-68	13
D4D-DD	82J	68-73	13
D4D-PS	83J	68-73	14
D4D-PS	22C	67-68	13
D4E-DD	27X	73-	13
D4E-PS	28X	73-	14
D5-DD	82H	67-73	16
D5-PS	84H	67-73	17
D5B-DD	23X	73-	17
D5B-PS	25X	73-	18
D6-DD	9U	47-59	14
D6B-DD	44A	59-67	15
D6C-DD	74A	63-67	17
D6C-PS	76A	63-67	18
D6C-DD	99J	67-75	19
D6C-PS	10K	67-75	20
D6D-DD	4X	75-	20
D6D-PS	4X	75-	21
D7-DD	3T	47-55	17
D7C-DD	17A	55-59	19
D7D-DD	17A	59-61	20
D7E-DD	47A	61-66	21
D7E-PS	48A	61-66	22
D7E-DD	47A	66-69	24
D7F-DD	93N	69-75	24
D7E-PS	48A	66-69	25
D7F-PS	94N	69-75	25
D7G-DD	91V	75-	26
D7G-PS	92X	75-	28
D8-DD	2U	46-53	21
D8-DD	13A	53-55	23
D8F-DD	14A	55-58	24
D8G-TC	15A	55-58	25
D8H-DD	36A	58-66	30
D8H-TC	35A	58-61	32
D8A-PS	46A	58-66	34
D8H-DD	36A	66-75	37
D8H-PS	46A	66-75	39
D8K-DD	76V	75-82	40
D8K-PS	77V	75-82	42
D8L-PS	53Y	82-	52

DD = Direct drive tranmission with clutch.
TC = Direct drive with torque converter.
PS = Power shift transmission.

These productivity indexes were supported by information from International-Hough, Dresser Industries and John Deere Industrial Equipment Co. International presented data that showed its new TD8E (in the small size class of bulldozers) to be 3 to 5 percent more productive in road construction than its TD9B, used in CDF's 1967 study (International-Hough, Dresser Industries 1982). Also, its new TD15C (in the medium size class of bulldozers) was said to be 21 percent more productive than its TD15B, used in CDF's study. These percentage increases agreed well with Caterpillar's figures for the two size classes of bulldozers.

John Deere presented evidence that its new 750 and 850 models (in the medium size class of bulldozers) were about 12 to 15 percent more efficient than medium bulldozers used in CDF's 1967 study (John Deere Industrial Equipment Co. 1982). Again, that increase agreed well with Caterpillar's figures for medium bulldozers.

Because of the independence of the studies made by the three manufacturers and the acceptably close agreement of their data, this study used that data for updating production rates from the CDF's and Steele's studies. The updated rates are shown in table 2 in the columns designated "New."

The production indexes (PI) used in table 2 were derived as follows:

Small bulldozers

CDF's 1967 study

Caterpillar D4D-PS (Ser. No. prefix 22C), used in study	PI = 13
Caterpillar D4E-PS (Ser. No. prefix 28X), new model	PI = 14
Change in PI (14–13/13)	PIΔ% = 7.7

Steele's 1954–59 study

Caterpillar D4-DD (Ser. No. prefix 6U), used in study	PI = 10
Caterpillar D4E-PS (Ser. No. prefix 28X), new model	PI = 14
Change in PI (14–10/10)	PIΔ% = 40.0

Medium bulldozers

CDF's 1967 study

Caterpillar D6C-PS (Ser. No. prefix 76A), used in study	PI = 18
Caterpillar D6D-PS (Ser. No. prefix 4X), new model	PI = 21
Change in PI (21–18/18)	PIΔ% = 16.7

Steele's 1954–59 study

Caterpillar D6-DD (Ser. No. prefix 9U), used in study	PI = 14
Caterpillar D6D-PS (Ser. No. prefix 4X), new model	PI = 21
Change in PI (21–14/14)	PIΔ% = 50.0

Large bulldozers

Steele's 1954–59 study

Caterpillar D7C-DD (Ser. No. prefix 3T), used in study	PI = 19
Caterpillar D7G-PS (Ser. No. prefix 92X), new model	PI = 28
Change in PI (28–19/19)	PIΔ% = 47.4

Preparing New Curves of Adjusted Production Rates

The adjusted production rates in table 2 appeared to be reasonable and ready for use by fire management planners. Because the adjusted rates came from two separate studies and were based on different sets of adjustment factors, it seemed prudent to reexamine them. New curves were drawn for each fuel model using the "new" rates from table 2.

The curves for some fuel models were very close in several instances for medium and small bulldozers.

(Although these curves are not showing, the "new" rates in table 2 reveal the close relationships.) Consequently, the curves for fuel models 1, 2, 3, and 8 were combined with that of fuel model 5 by simple averaging. The same procedure was used to combine the curves of fuel models 6 and 7, and that of fuel model 4 with the one for fuel models 9, 11, and 12. These combinations, shown in figures 12 to 14, all appeared reasonable for two reasons:

1. The rates in table 2 were close in each combination.
2. Considering all aspects of their descriptions (Anderson 1982), the fuel models within each combination appeared to offer about the same resistance to fireline construction by bulldozers.

Future verifying tests in field operations should reveal whether or not the combinations are real and satisfactory.

The only major variance was in slope class 3, downslope, in the combination of fuel model 4 with fuel models 9, 11, and 12 (table 2). The difference came from the CDF's original field data for fuel model 4. The data caused the production curves for both medium and small bulldozers to fall off very gradually at slope class 3, downslope, an anomaly in comparison with the other CDF curves. (See curve for "high brush" in figures 10 and 11.) Checking that anomaly with the CDF personnel who conducted the 1967 test revealed that despite and because of the meager data, the **gradual** fall-off of production rates was not real. More real was the **sharp** fall-off shown in figures 12 to 14. The sharp fall-off reflects the decreasing capability of bulldozers to back up and empty their blades on downslopes of more than 40 percent.

Rearranging Bulldozer Fireline Production Rates

Updated production rates from figures 12 to 14 were then arranged into a usable format in table 4. This format might be appropriate for future editions of fireline handbooks.

Appendix A includes a table of suggested fireline production rates for bulldozers manufactured from 1965 to 1975 (table 5), which should be useful for two reasons:

1. Fire protection agencies indicated that many bulldozers manufactured during that period will continue to be used for several years.
2. Rates for these bulldozers published in current fireline handbooks appeared inaccurate and incomplete.

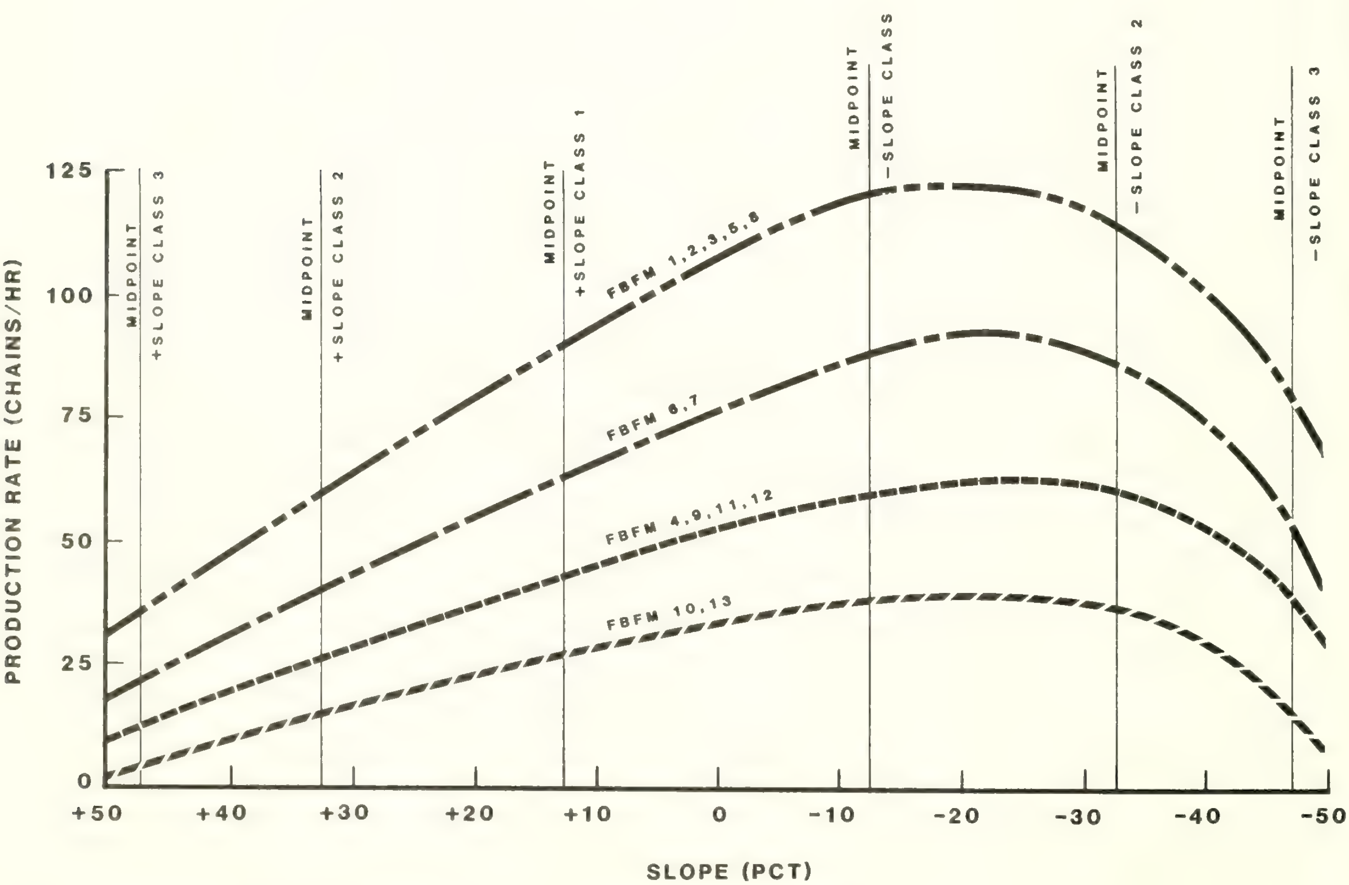

Figure 12.—Base rates for large bulldozer fireline production (single pass) adjusted to fit bulldozers manufactured since 1975.

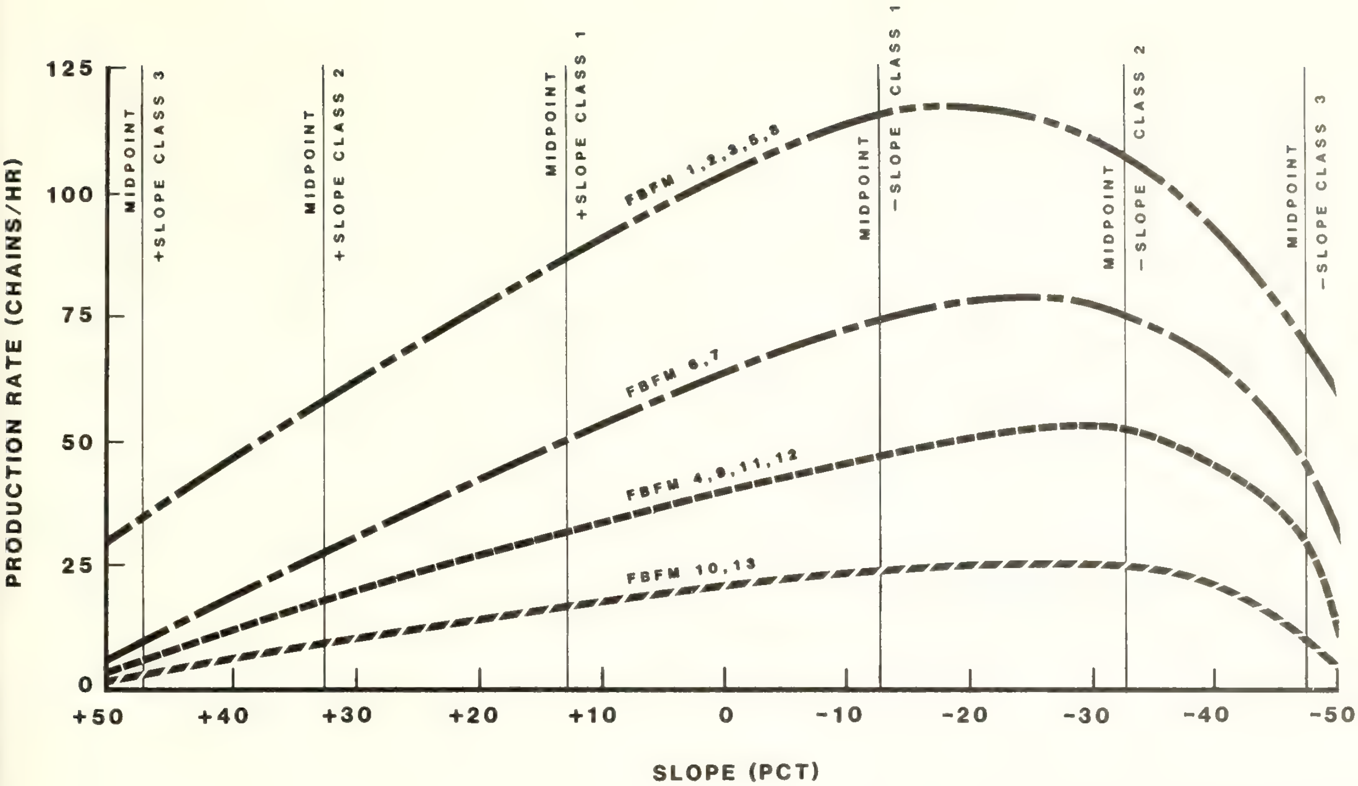

Figure 13.—Base rates for medium bulldozer fireline production (single pass) adjusted to fit bulldozers manufactured since 1975.

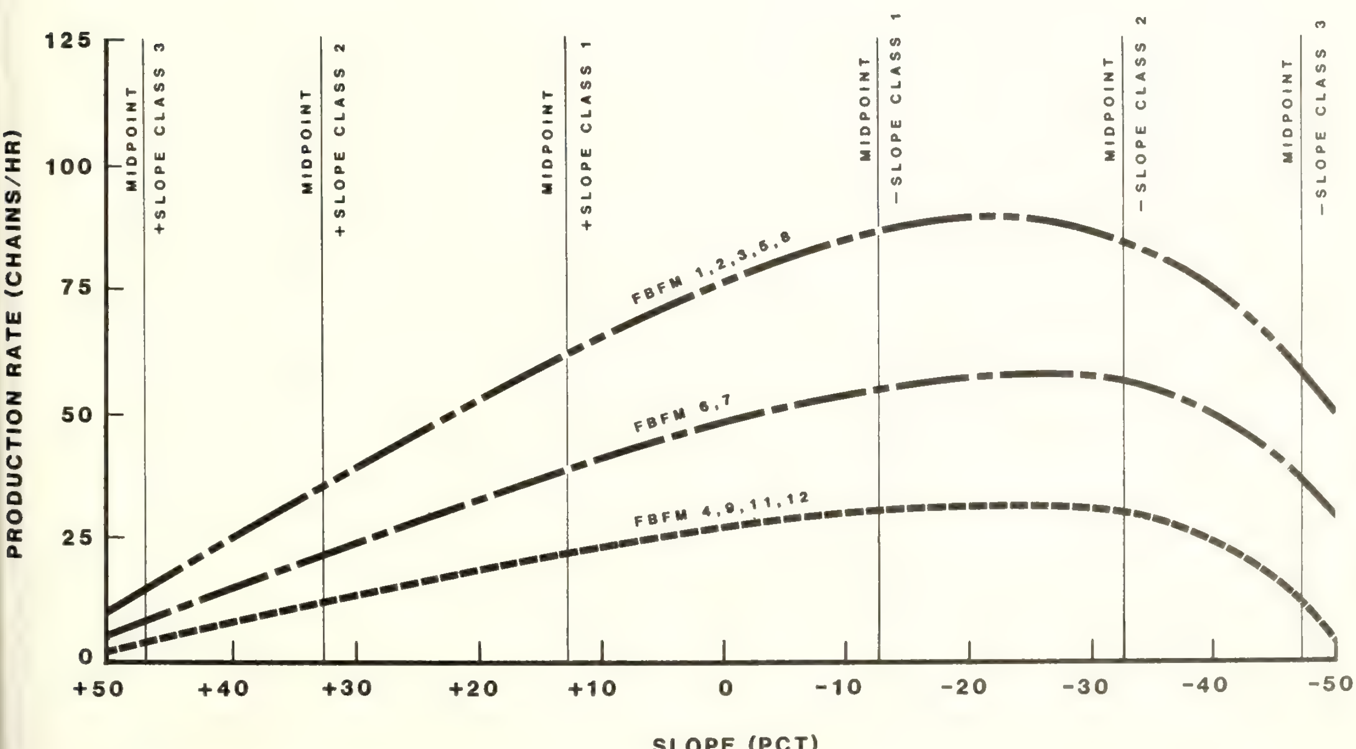

Figure 14.—Base rates for small bulldozer fireline production (single pass) adjusted to fit bulldozers manufactured since 1975.

Verifying Updated Rates of Fireline Production

The rates in table 4 (and in table 5 in appendix A) are "paper rates," derived in the manner described in this report. There remains the task, therefore, of verifying those rates. Because of limited funds, extensive field tests are not possible. Instead, a limited number of constructed firelines will be measured in abbreviated field tests that have yet to be planned and conducted. In the meantime, the revised bulldozer production rates in tables 4 and 5 are available for use in operational situations.

DISCUSSION AND SUMMARY

The purpose of this study was to provide fireline production rates for modern bulldozers. To accomplish that task, the following steps were taken:

1. Bulldozers were arbitrarily classed as small, medium, or large according to certain criteria.
2. Past studies were sought that presented production rates for bulldozers and described how the rates were obtained. Three such studies were found. Two of them, one by Robert W. Steele in 1954-59 and another by the California Department of Forestry (CDF) in 1967, were chosen to provide base rates for this study (figs. 2-6).
3. The production curves from Steele's older study were subjectively changed by a small amount to match the capabilities of the more modern bulldozers used in the CDF's tests (figs. 9-11).
4. The production curves in figures 9 to 11 were related subjectively to the 13 fire behavior fuel models based upon descriptions of vegetation encountered in Steele's and the CDF's studies (table 1).
5. The production curves from the two base studies were used to tabulate fireline production rates according to bulldozer size, the 13 fire behavior fuel models, and the first three slope classes of the National Fire-Danger Rating System (table 2).
6. The fireline production rates from the two base studies were updated by multiplying them by factors related to "production indexes" developed for various models of bulldozers. The "production indexes" were obtained from bulldozer manufacturers who had developed them for other earth-moving applications (table 3). The updated rates were added to table 2.
7. The updated rates in table 2 were used to prepare new curves of fireline production rates (figs. 12-14). Some curves were subjectively combined or adjusted further.
8. The new curves were then used as a base to prepare a final table of bulldozer fireline production rates classified by bulldozer sizes, fire behavior fuel models, and slope classes separated by upslope and downslope (table 4). Table 4 was prepared for bulldozers

Table 4.—Bulldozer fireline production rates (single pass) for bulldozers manufactured since 1975

Fire behavior fuel model	Slope class 1 (0%-25%) Up	Slope class 1 (0%-25%) Down	Slope class 2 (26%-40%) Up	Slope class 2 (26%-40%) Down	Slope class 3 (41%-55%) Up	Slope class 3 (41%-55%) Down
	———————Chains per hour———————					
Small bulldozers						
1, 2, 3	63	88	36	88	14	61
4	22	29	12	30	3	22
5	63	88	36	88	14	61
6	39	59	22	62	8	42
7	39	52	22	56	8	35
8	63	88	36	88	14	61
9, 11, 12	22	30	12	30	3	11
Medium bulldozers						
1, 2, 3	88	118	58	112	35	73
4	32	47	18	53	5	31
5	88	118	58	112	35	73
6	51	75	26	78	9	48
7	51	75	27	78	9	48
8	88	118	58	112	35	73
9, 11, 12	32	47	18	53	5	31
10, 13	17	23	10	25	3	11
Large bulldozers						
1, 2, 3	91	124	62	118	35	83
4	43	60	27	62	12	40
5	91	124	62	118	35	83
6, 7	63	91	41	90	22	57
8	91	124	62	118	35	83
9, 11, 12	43	60	27	62	12	40
10, 13	27	38	15	34	4	16

manufactured since 1975. Appendix A includes a similar table prepared for bulldozers manufactured from 1965 to 1975 (table 5).

Because the production rates in tables 4 and 5 were derived mathematically, there remains the task of verifying them through abbreviated field trials.

The data and procedure presented in this report were reviewed by field personnel involved in fire management. Their consensus was that our approach to adjusting older production rates to fit more modern bulldozers was reasonable. Further, the amount and direction of adjustment also appeared intuitively reasonable.

Verification from field tests and feedback from fire managers who use the new rates will lead to further adjustment of the rates, making them more accurate and more useful. The adjustments, however, cannot take into account the many small variables affecting the rate of fireline construction. Tables of production rates should not be overly refined or difficult to use.

The bulldozer fireline production rates developed in this study will probably require further adjustment and correction. Even so, they should be more useful for fire management planning than those in current fireline handbooks.

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APPENDIX A

Suggested Fireline Production Rates for Bulldozers Manufactured from 1965 to 1975

The principal objective of this study was to develop fireline production rates for newer bulldozers manufactured since 1975. In working toward that objective, however, it became apparent that there was also a need for a revised table of production rates for older bulldozers manufactured from 1965 to 1975.

The inventory of bulldozers owned or controlled by public fire protection agencies revealed that a large number of older bulldozers will continue to be used for several years. Reduced budgets are requiring State agencies, especially, to retain their bulldozers much longer than originally planned. Therefore, a revised table of fireline production rates is offered for bulldozers manufactured from 1965 to 1975 (table 5).

Table 5.—Bulldozer fireline production rates (single pass) for bulldozers manufactured from 1965-75

Fire behavior fuel model	Slope class 1 (0%-25%) Up	Slope class 1 (0%-25%) Down	Slope class 2 (26%-40%) Up	Slope class 2 (26%-40%) Down	Slope class 3 (41%-55%) Up	Slope class 3 (41%-55%) Down
	Chains per hour					
Small bulldozers						
1, 2, 3	63	88	36	88	14	61
4	22	29	12	30	3	22
5	63	88	36	88	14	61
6	41	57	22	58	8	37
7	41	57	22	58	8	37
8	63	88	36	88	14	61
9, 11, 12	22	30	12	29	3	13
Medium bulldozers						
1, 2, 3	85	112	57	107	34	71
4	30	44	16	50	4	30
5	85	112	57	107	34	70
6	49	72	26	75	7	47
7	49	72	26	75	7	47
8	85	112	57	107	34	71
9, 11, 12	30	44	16	50	4	30
10, 13	17	25	11	24	3	9
Large bulldozers						
1, 2, 3	82	111	55	105	32	74
4	38	54	24	55	11	36
5	82	111	55	105	32	74
6, 7	57	82	37	80	20	51
8	82	111	55	105	32	74
9, 11, 12	38	54	24	55	11	36
10, 13	24	34	13	30	4	14

Table 5 was developed with the same procedure as that used for table 4. The only difference was in the use of production indexes from table 3 of bulldozer models manufactured from 1965 to 1975:

Small bulldozers

CDF's 1967 study

Caterpillar D4D-PS (Ser. No. prefix 22C), used in study — PI = 13

Caterpillar D4D-PS (Ser. No. prefix 83J), representative model — PI = 14

Change in PI (14–13/13) — PIΔ% = 7.7

Steele's 1954–59 study

Caterpillar D4D-DD (Ser. No. prefix 6U), observed in study — PI = 10

Caterpillar D4D-PS (Ser. No. prefix 83J), representative model — PI = 14

Change in PI (14–10/10) — PIΔ% = 40.0

Medium bulldozers

CDF's 1967 study

Caterpillar D6C-PS (Ser. No. prefix 76A), used in study — PI = 18

Caterpillar D6C-PS (Ser. No. prefix 10K), representative model — PI = 20

Change in PI (20–18/18) — PIΔ% = 11.1

Steele's 1954–59 study

Caterpillar D6C-DD (Ser. No. prefix 9U), observed in study — PI = 14

Caterpillar D6C-PS (Ser. No. prefix 10K), representative model — PI = 20

Change in PI (20–14/14) — PIΔ% = 42.9

Large bulldozers

Steele's 1954–59 study

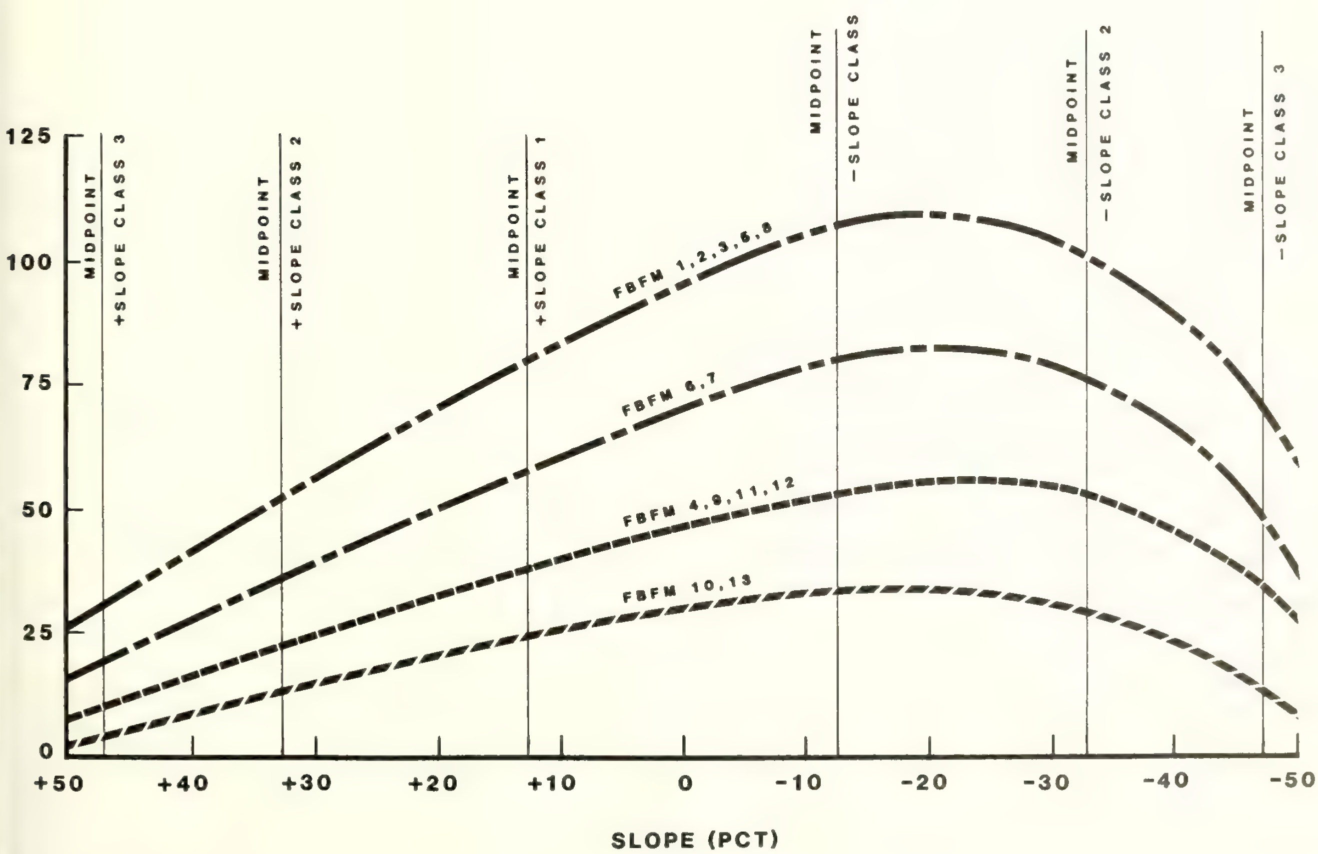
Caterpillar D7C-DD (Ser. No. prefix 3T), observed in study — PI = 19

Caterpillar D7F-PS (Ser. No. prefix 94N), new model — PI = 25

Change in PI (25–19/19) — PIΔ% = 31.6

These production index changes produced a set of adjusted rates specifically for bulldozers manufactured from 1965 to 1975. These adjusted rates are shown in graphic form in figures 15 to 17, corresponding to figures 12 to 14 for bulldozers manufactured since 1975. The rates in table 5 were then read from figures 15 to 17.

The rates in table 5 are as tentative as those in table 4, and for the same reasons. Consequently, the production rates shown in table 5 will also be sample-tested in abbreviated field tests as opportunities arise. In keeping with the principal objective of this study, however, priority will be given to sample-testing the newer models of bulldozers.



igure 15.—Base rates for large bulldozer fireline production (single pass) adjusted
fit bulldozers manufactured from 1965 to 1975.

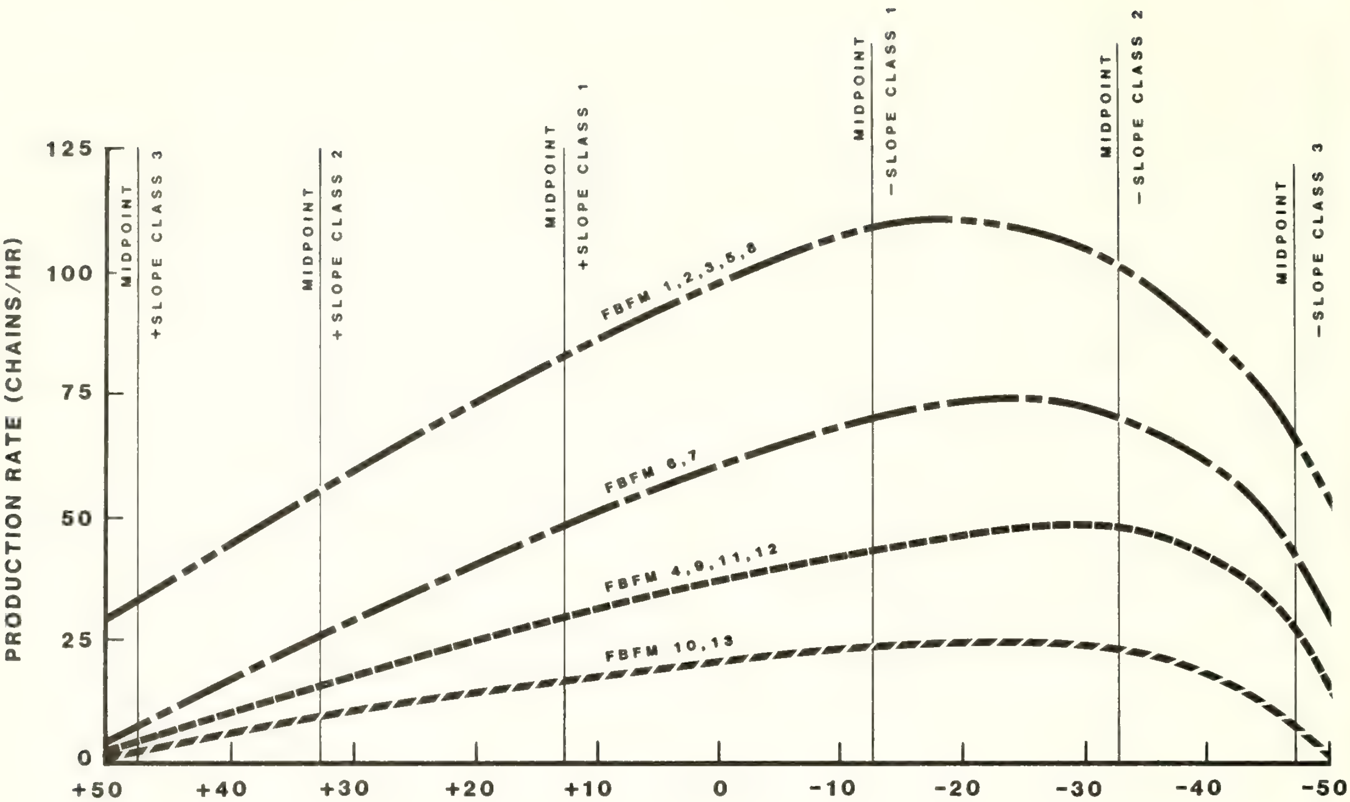


Figure 16.—Base rates for medium bulldozer fireline production (single pass) adjusted to fit bulldozers manufactured from 1965 to 1975.

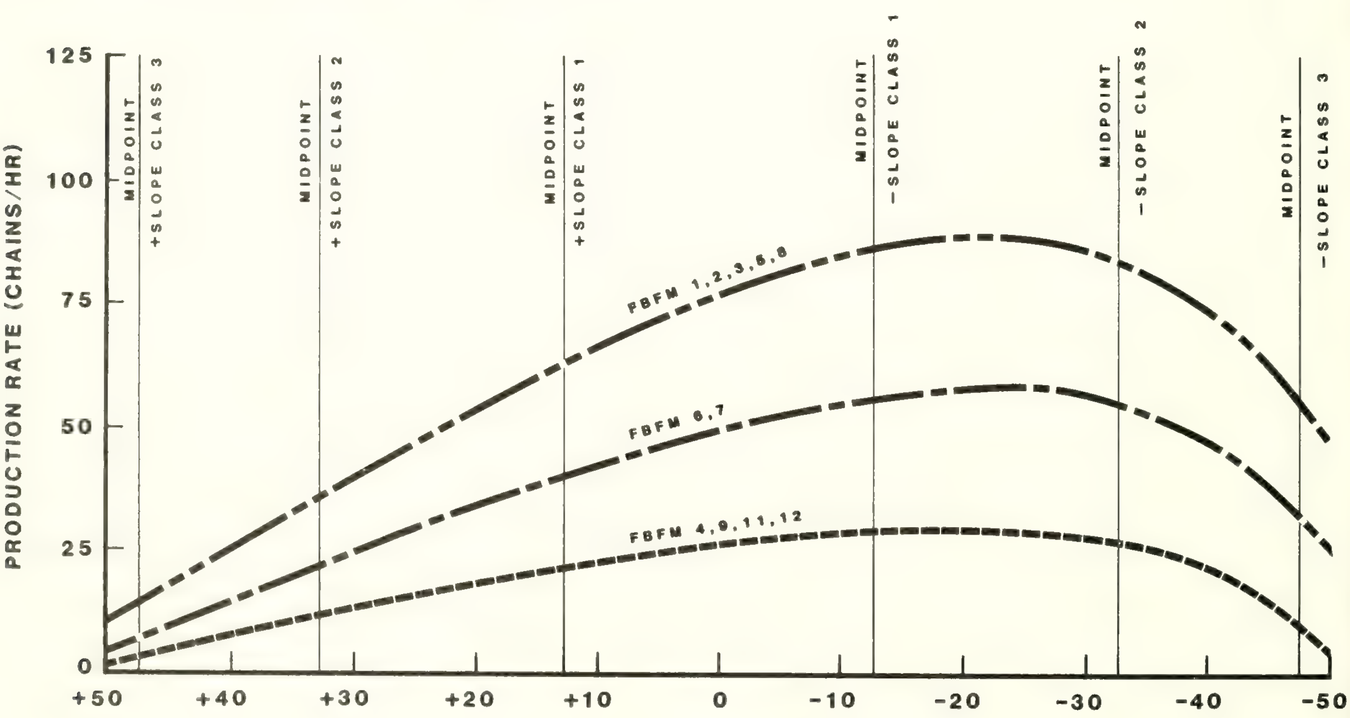


Figure 17.—Base rates for small bulldozer fireline production (single pass) adjusted to fit bulldozers manufactured from 1965 to 1975.

APPENDIX B

Relationships of Fire Behavior Fuel Models to Fuel Models of the National Fire-Danger Rating System (Anderson 1982)

NFDRS FUEL MODELS	FIRE BEHAVIOR FUEL MODELS													
	1	2	3	4	5	6	7	8	9	10	11	12	13	
A W. ANNUALS	X													GRASS
L W. PERENNIAL	X													GRASS
S TUNDRA	X					3rd			2nd					GRASS
C OPEN PINE W/GRASS		X							2nd					GRASS
T SAGEBRUSH W/GRASS		X			3rd	2nd								GRASS
N SAWGRASS			X											GRASS
B MATURE BRUSH (6FT)				X										SHRUB
O HIGH POCOSIN				X										SHRUB
F INTER. BRUSH					2nd	X								SHRUB
Q ALASKA BLACK SPRUCE						X	2nd							SHRUB
D SOUTHERN ROUGH						2nd	X							SHRUB
H SRT-NDL CLSD. NORMAL DEAD								X						TIMBER
R HRWD. LITTER (SUMMER)								X						TIMBER
U W. LONG-NDL PINE									X					TIMBER
P SOUTH, LONG-NDL PINE									X					TIMBER
E HRWD. LITTER (FALL)									X					TIMBER
G SRT-NDL CLSD. HEAVY DEAD										X				TIMBER
K LIGHT SLASH											X			SLASH
J MED. SLASH												X		SLASH
I HEAVY SLASH													X	SLASH
	GRASS			SHRUB				TIMBER			SLASH			

Phillips, Clinton B.; Barney, Richard J. Updating bulldozer fireline production rates. General Technical Report INT-166. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 21 p.

Provides tables and performance curves for estimating rates of fireline construction for bulldozers built between 1965 and 1983. Data are derived from productivity indexes furnished by bulldozer manufacturers and have not been confirmed by field trials. Construction rates are categorized by dozer size, fuel density, and slope.

KEYWORDS: bulldozers, fireline, production, rate of construction, wildfire, tractor, tracked equipment

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BEHAVE: Fire Behavior Prediction and Fuel Modeling System—
FUEL Subsystem

Robert E. Burgan
Richard C. Rothermel

PREFACE

Over the past decade the science of fire modeling has made great advances. The 13 original fire behavior fuel models have been used successfully to represent a wide array of fuel types in the United States. Nevertheless, fire managers, who are using fire predictions in an increasing number of applications, have found that existing fuel models do not adequately match some fuel situations. They therefore have developed a need for techniques that will enable them to modify existing fuel models or to devise entirely new ones. The purpose of this publication is to provide them with this capability.

The FUELS subsystem of BEHAVE contains programs that will enable fire managers to assemble fuel models and test their performance before releasing them for operational use. Fuel modeling is not yet a rigorous process; consequently science and good judgment are both needed. Nevertheless, pilot tests have shown that the methods are ready for application in the field by well-trained personnel.

The programs contain new and simplified procedures for examining fuels in the field and developing fuel models. It is not always necessary to construct new models, however; modifications to existing models may be sufficient in some cases, while in others more rigorous field inventory procedures may be desirable. There are four ways to obtain a fuel model for operational use in BEHAVE:

1. Choose one of the 13 standard models.
2. Modify one of the 13 standard models.
3. Use measured data taken by inventory techniques.
4. Use the new fuel modeling procedures described in this manual.

The fastest solution is choosing one of the standard 13 models (Anderson 1982). If that does not satisfy the user, the most representative model of the 13 can be modified. For example, one can change loading and depth, add green fuel, make it a dynamic model, and so on. If modification is not satisfactory, the next fastest expedient would be to use our new procedures. Although any method of measuring and modeling fuels yields only approximate answers, our new procedures are simple, inexpensive, and rapid to use. But if the user prefers to inventory, or to use previously inventoried data, the programs will accommodate the fuel loads by size class and will assist the user in providing information needed to assemble a complete fuel model.

Several features built into the modeling program contribute to reasonable fuel models and fire predictions:

1. The system will build either static or dynamic models. This overcomes the problem that the present 13 models are primarily designed for the time of year when fuels are cured.
2. The procedures are designed to combine the data from mixtures of litter, grass, shrubs, and slash to produce a composite model. In this process, depths and loads of each type are adjusted by area covered. Such a model should be carefully examined, tested, and its fire predictions compared with field data and standard models--a task simplified by the FUEL programs.
3. If the fuels occur in individual patches, models may be built to describe the dominant fuel cover and the fuel that interrupts the dominant fuel. BURN will use both in the two-fuel-model concept described by Rothermel (1983).
4. The slash procedures utilize several techniques for estimating load. These are patterned after the research of Brown (1974) and include the number of intercepts as well as load and depth relationships. They also can utilize fuel photo series such as those developed by Fischer (1981a, 1981b, 1981c), Koski and Fischer (1979), and Maxwell and Ward (1978a, 1978b, 1979, 1980).

The site-specific fuel modeling techniques described in this manual are appropriate for constructing fire behavior fuel models only. They are not intended for constructing National Fire-Danger Rating fuel models. Basic differences between the mathematical equations used in the fire danger and fire behavior computer programs preclude this possibility. These differences occur primarily in the procedures for weighting the influence of various fuel size classes, thus producing outputs meant to have different interpretations. As a result, to reasonably represent the same "actual" fuels situation, a fire danger fuel model must be assigned different values than a fire behavior fuel model. Thus, fuel models are applicable only with the fire processor used to construct them, and the fire danger processor is not part of the BEHAVE system.

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RICHARD C. ROTHERMEL received his bachelor of science degree in aeronautical engineering at the University of Washington in 1953 and his master's degree in mechanical engineering at Colorado State University, Fort Collins, in 1971. He served in the U.S. Air Force as a special weapons aircraft development officer from 1953 to 1955. Upon his discharge he was employed at Douglas Aircraft Co. as a designer and trouble shooter in the armament group. From 1957 to 1961 Rothermel was employed by the General Electric Co. in the aircraft nuclear propulsion department at the National Reactor Testing Station in Idaho. In 1961 he joined the Northern Forest Fire Laboratory where he has been engaged in research on the mechanisms of fire spread. He was project leader of the fire fundamentals research work unit from 1966 until 1979 and is currently project leader of the fire behavior research work unit at the fire laboratory.

RESEARCH SUMMARY

The BEHAVE system is a set of interactive computer programs that (1) permit construction of site-specific fire behavior fuel models, and (2) contain state-of-the-art wildland fire behavior prediction procedures that will be periodically updated. This manual documents the fuel modeling portion of BEHAVE. New and simplified procedures for collecting fuels data are described. Instructions are provided for the use of two programs: (1) NEWMDL, which is used to construct a "first draft" fuel model from raw field data, and (2) TSTMDL, which is used to test new fuel models and adjust them until they produce reasonable fire behavior predictions. An extensive section describes concepts and technical aspects of fuel modeling.

CONTENTS

BEHAVE: Fire Behavior Prediction and Fuel Modeling System—
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INTRODUCTION

The site-specific fuel modeling programs described in this manual are part of the BEHAVE System--a series of interactive fire behavior computer programs for estimating wildland fire potential under various fuels, weather, and topographic situations. The field procedures and the two interactive computer programs described here--NEWMDL and TSTMDL--provide fire managers the capability to construct site-specific fuel models and to test their fire behavior characteristics under a variety of simulated environmental conditions. The BURN subsystem of BEHAVE described by Andrews (n.d.) is designed to use the fuel models developed in FUEL along with state-of-the-art fire prediction techniques for predicting fire behavior for operations, planning, or training. The general structure of the BEHAVE system and the relation of these programs to each other are illustrated in figure 1.

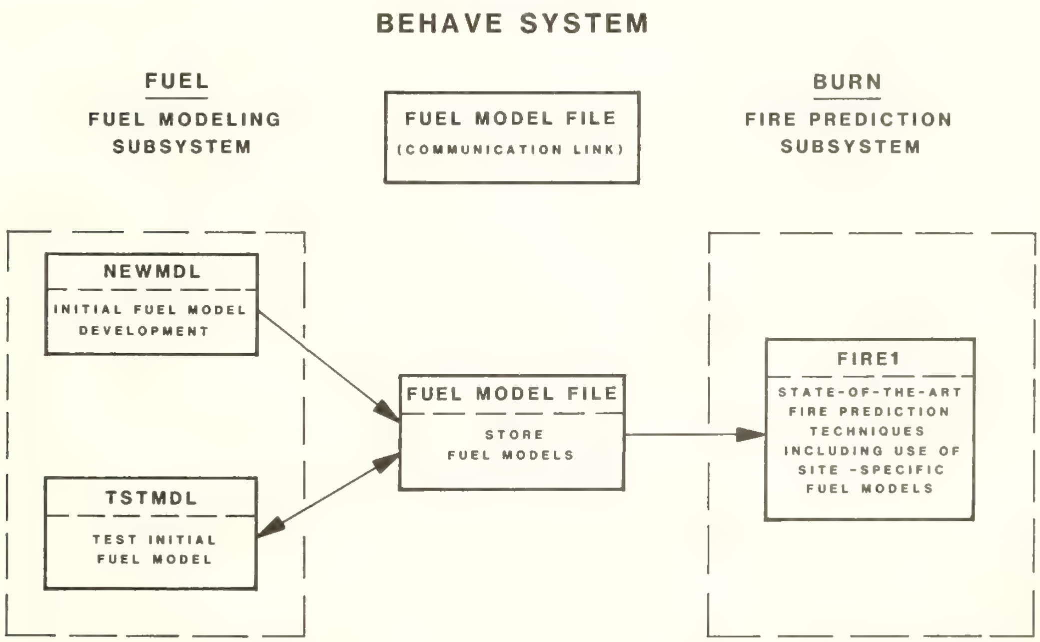

Figure 1.--General structure of the BEHAVE system. The BEHAVE system utilizes a "fuel model file" to give the fire prediction subsystem access to site-specific fuel models constructed in the fuel modeling subsystem.

Until now, the library of fire behavior fuel models available to match fuels situations encountered in the field has been limited to the 13 stylized fuel models developed at the Northern Forest Fire Laboratory (Anderson 1982) or specialized models developed for certain

parts of the country such as the southern California brush models (Rothermel and Philpot 1973; Cohen, review draft) or the southern rough models (Hough and Albini 1978). These fuel models have served well in a variety of applications, but methods are needed to accommodate a wide array of fire management activities.

Careful consideration should be given to the methods of obtaining a fuel model. The matters of cost, time, and values at risk should be considered. The following guidelines are suggested to aid in the choice:

Use the standard 13 models without modification:

a. To illustrate fire behavior of different fuels in general without reference to any particular site.

b. For estimating fire behavior when there are no other fuel models for the area and no time to develop them.

c. When some of the standard models have been found to work well for fuels in an area.

d. For instruction and training about fuels or fire behavior.

Use one of the standard 13 models with modifications:

a. When experience indicates better representation of fire behavior requires a change, such as . . .

- changing a grass model from static to dynamic,
- adding live fuel to a model such as slash,
- adjusting load and/or depth to better represent local fuels, i.e., 3-ft brush at 10 tons per acre (T/A) rather than 6-ft at 25 (T/A),
- increasing the heat content of very flammable brush.

Use inventory techniques as developed by Brown (1974) and Brown and others (1982):

a. For fuel appraisal, or whenever it is important to compare the relative differences in flammability between fuels complexes.

b. For developing fuel models where fuels are relatively uniform and values at risk warrant highly accurate fuel models for fire prediction.

Use the new procedures in NEWMDL:

a. When an estimate of fire behavior is needed but the time and expense of inventory is not cost effective.

b. For developing a fuel model to produce fire behavior predictions that are consistent with observed behavior in fuels difficult to model by other means.

c. For constructing fire behavior fuel models to mimic the behavior of the National Fire-Danger Rating System (NFDRS) models used in an area.

If one of the standard 13 models is to be used, it may be called directly in both BURN and TSTMDL.

If one of the standard 13 models is to be modified, follow the TSTMDL instructions.

If the new fuel modeling procedures are to be used, follow the NEWMDL instructions.

If fuel load inventory data is to be used, it is entered in NEWMDL when you are asked for loading by size class.

Successful fuel modeling requires a working knowledge of both the mathematical fire spread model (Rothermel 1972) and the fire behavior characteristics of any given vegetation type, under a variety of environmental conditions. Therefore, fuels and fire behavior specialists are the intended operational users of the BEHAVE system. Nevertheless, the BEHAVE system may also serve as an effective educational tool for those interested in learning more about how fuels and environmental parameters influence fire behavior prediction.

The new procedures introduced in NEWMDL use a few key observations about one or more of four major fuel components: grass,

litter, shrubs, or slash. NEWMDL prompts the user for values of the fuel descriptors in a sequence that gradually assembles the fuel model. Once assembled, the model can be tested in a variety of ways, including comparisons with any of the original 13 fire behavior models.

The philosophy used in developing the new fuel modeling subsystem has been to assemble a fuel model with minimal field sampling. To accomplish this, the programs have the flexibility to allow entry of information from:

* previously inventoried fuels data
* relationships compiled from past research
* new data obtained using field procedures described in this manual.

The new field procedures are simplified through the use of a photo series to help determine general vegetation type and density; ocular assessments of the percentage of area covered by grass, litter, shrubs, or slash; and simple measurements of their approximate depths, or if available from inventory data, loads. Then load/depth relationships defined in NEWMDL are used to determine depths from loads or loads from depths. Load assessment will be most accurate if measured. Depth is more difficult to estimate (Brown 1982). For instructional purposes, where the model will not be keyed to a site, this consideration is not important. Sample load/depth relationships are illustrated in figure 2. The NEWMDL program contains a more complete representation of the data in this figure. The relationships in figure 2 show the distinction between fuel types, but there is, of course, considerable variation in the load/depth relationship for any one fuel type. Consequently, the first approximation may not produce reasonable fire behavior and the values may require adjustment.

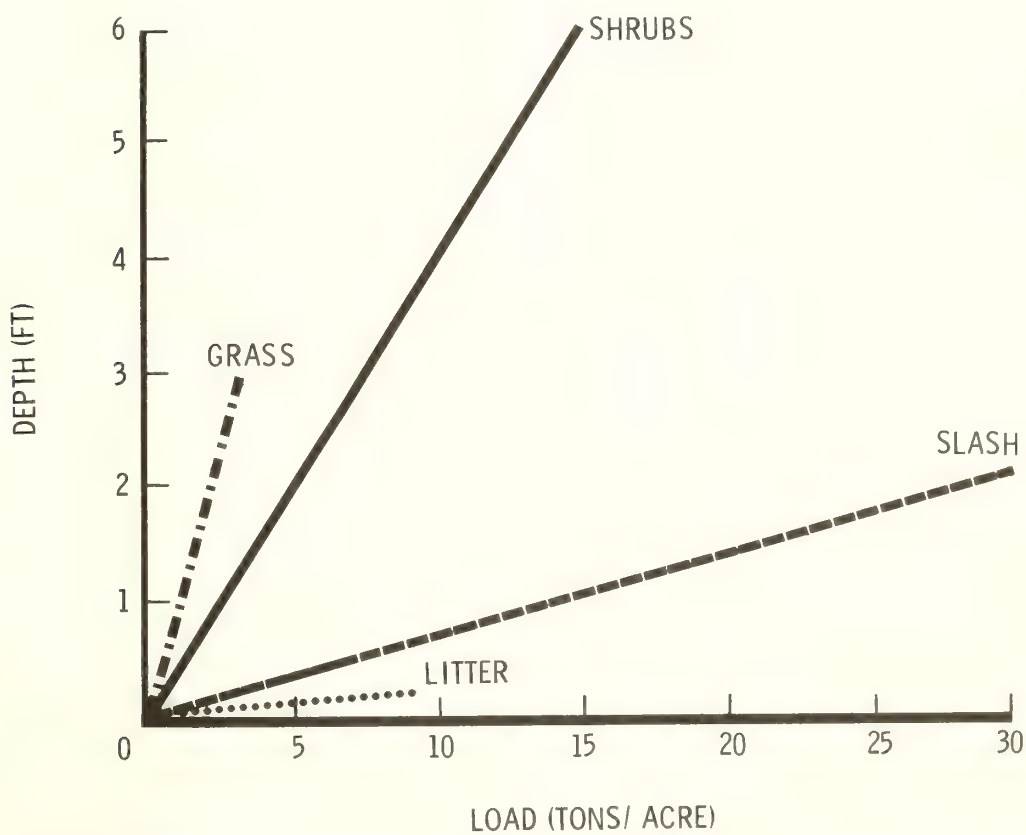

Figure 2.--An example of load/depth relationships established for general fuel types and used in the NEWMDL program.

The interactive computer programs contribute to fuel modeling in several ways: breaking total load into loads by size (timelag) class, estimating heat content, surface-area-to-volume ratios, moisture of extinction, and testing and adjusting a fuel model until it provides fire behavior estimates that closely match known fire behavior for the fuel complex it represents.

Either dynamic or static fuel models can be constructed. Dynamic models transfer fuel between the live herbaceous and the 1-hour timelag categories as appropriate for seasonal changes in the moisture content of herbaceous fuels. This process uses the herbaceous fuel load transfer algorithm developed for the 1978 National Fire-Danger Rating System (Burgan 1979). Static fuel models have fixed loads in all fuel categories. The 13 fire behavior fuel models are an example of static models that were designed for use during the more critical portion of a fire season. The fuel loads in all live and dead classes remain constant regardless of fuel moisture in this type of fuel model.

Both NEWMDL and TSTMDL meet the constraints imposed by 80-column-by-24-row video display terminals and 80-column printing terminals. Although graphics are employed, specialized graphics terminals are not required. This generality was achieved at the expense of graphics resolution.

To increase "user friendliness," the fuel modeling programs are tutorial and have both "wordy" and "terse" response modes. The "wordy" mode provides full prompting, which is helpful for first time or occasional users, while the "terse" mode produces minimal prompting desired by experienced users. In addition, program control is through keywords that are descriptive of the task to be performed. The details of these features are provided in the sections on operating NEWMDL and TSTMDL.

Once an acceptable fuel model has been developed, it can either be used with the BURN subsystem of BEHAVE, or be recorded on a magnetic card and used with the fire behavior program developed for the TI-59 calculator (Burgan 1979). Instructions for using the TI-59 to predict fire behavior are given by Rothermel (1983). Instructions for testing and verifying fire behavior predictions with any fuel model are given by Rothermel and Rinehart (1983).

FUEL MODEL FILE--THE COMMON LINK FOR THE BEHAVE SYSTEM

Fuel model files provide a communications link between the NEWMDL, TSTMDL, and BURN programs of the BEHAVE system (fig. 1).

Both NEWMDL and TSTMDL enable you to build and save fuel models in a disk file for easy access. You may manage the contents of the file by listing, adding, replacing, or deleting fuel models. The first record in each fuel model file is a "header" containing (1) a password and (2) a short description of the file.

The password is user-defined and must be matched before fuel models are added to, deleted from, or replaced in a file. This protects users from unauthorized or accidental alteration of their file. Nevertheless, there is no restriction on creating new fuel models for your own file, or listing the names and numbers of models currently in any file.

The file description provides very general information about the models in the file. They might be described as being for a particular Forest, Ranger District, or project.

Use of keyword "FILE" may be made from any of the three programs. TSTMDL will allow you to:

1. Get a previously built site-specific fuel model.
2. List the names and numbers of fuel models in the file.
3. Change a fuel file header.
4. Add the fuel model just built to the fuel model file.
5. Replace a fuel model in the file.
6. Delete a model from the fuel model file.

NEWMDL can perform all of these functions except get a previously built fuel model.

The BURN program is intended to be used with previously constructed fuel models, in an operational mode. It will access models in the file, but cannot alter the file.

The structure of the fuel model file is described in appendix D.

PROGRAM NEWMDL

General Concept

Construction of a new site-specific fuel model should begin by using program NEWMDL. NEWMDL defines initial values for fuel model parameters under user control. NEWMDL is especially helpful if extensive fuel inventory information is not available and permits construction of a "composite" fuel model containing any combination of litter, grass, shrub, or slash.

Although most fuel models can be constructed with the standard three dead and two live fuel classes, special cases may arise where it is necessary to enter data for two different sizes of 1-h fuels. An example is ponderosa pine *(Pinus ponderosa)* slash, which may have fine needles, but rather coarse twigs.

When such a model is being built, the program assumes measured data is available for direct input. Upon completion of data entry, NEWMDL will "condense" the four-dead, two-live class model to a standard three-dead, two-live class model for use in the BEHAVE system or the TI-59. The "condensed" model should produce fire behavior very similar to a four-dead fuel class model.

Litter, grass, and shrub fuel information can be entered as follows:

1. Direct input of dead fuel loads by timelag class, live loads as woody or herbaceous, and fuel depth for each vegetation type.
2. Total load by vegetation type--depth calculated
3. Total depth by vegetation type--load calculated.

Option 1 is used when fuel inventory data are available for both load by size class and depth by fuel component--grass, litter, or shrub. The program then calculates a mean depth for the composite fuel complex in addition to suggesting reasonable values for heat content, surface-to-volume ratios, and moisture of extinction. Options 2 or 3 are used when only loads or only depths are known. In fuels with poorly defined depths, such as forest litter, option 3 should be used cautiously and the calculated loads checked for reasonableness.

Slash fuels may also be entered directly by load within each timelag class and depth (option 1) if complete inventory data are available. Otherwise relationships developed for intermountain conifers (Brown 1978; Albini and Brown 1978) are used to estimate the slash fuels. These relationships permit entry of:

1. Total slash load.
2. Total 10-hour timelag load only.
3. Ten-hour timelag load by species.
4. Number of 10-hour intercepts per foot, by species.

The program then assists the user in partitioning the total load into size classes and in reducing slash depth and twig and foliage retention, as a function of harvest method and slash age.

One hundred percent ground coverage is assumed for total litter, grass, shrub, or slash loads initially entered into the program. Such coverage by a single fuel component is possible, but not necessarily the case. When less than 100 percent ground coverage is specified for any fuel component, the load and the depth of that component will be reduced accordingly. Both load and depth must be reduced so the bulk density (amount of fuel [pounds] per cubic foot) of fuel bed will remain the same. In addition, the same ground area may be covered by more than one component (example: grass, litter, and slash). Subsequent program operations sum the loads for each component, and partition them among the size classes.

The final output of NEWMDL is a display of the completed fuel model (fig 3). The model should be exercised in the TSTMDL program to examine its fire behavior characteristics and to possibly adjust some parameters.

A detailed explanation of the weighting procedures used to produce the completed fuel model from the users' input is provided in appendix E.

```
                  CURRENT VALUES OF FUEL MODEL PARAMETERS
DYNAMIC 14. SAMPLE MODEL                               BY: BURGAN

      LOAD (T/AC)              S/V RATIOS                        OTHER
  ------------------     ---------------------     ---------------------------------
  1 HR           4.87    1 HR          1880.       DEPTH (FEET)                 0.94
  10 HR          1.00    LIVE HERB     1900.       HEAT CONTENT (BTU/LB)       8000.
  100 HR         0.89    LIVE WOODY    1700.       EXT MOISTURE (%)              17.
  LIVE HERB      0.83    S/V = (SQFT/CUFT)
  LIVE WOODY     1.13
```

Figure 3.--NEWMDL output. The final output of the NEWMDL program is a display of the completed fuel model. At this point the model can be saved in a fuel model file.

Structure and Operation

The specific procedure for accessing your computer and the NEWMDL program must be obtained from your computer specialist. Once started, you will find the interactive, tutorial nature of NEWMDL eliminates the need for a detailed explanation of program operation. Nevertheless, a general overview of program structure and operation is helpful.

You will first be asked to enter your name (maximum of 20 letters) and indicate whether you want to use the "TERSE" mode (minimal prompting for experienced users) or the "WORDY" mode (full prompting for new users). After accepting or declining a list of keywords used for program control, you will be asked whether you want to build a model with one or two sizes of fine (1-h) fuel. Normally one size of fine fuel should be selected. A number and name must then be entered for the proposed fuel model. Acceptable numbers are 14 through 99. Numbers 1 through 13 are reserved for the 13 fire behavior fuel models (Anderson 1982).

Program control is through the use of keywords. This provides a great deal of operational flexibility. Any keyword above the dashed line in the following tabulation can be entered whenever the message "CONTROL SECTION. KEYWORD?" is printed. There is no specific order in which litter, grass, shrub, or slash fuel loads must be determined. In addition, you can ask for a keyword list, set terse or wordy mode, display current values of the four fuel components, restart the program, access the fuel model file, or quit the session, whenever you are prompted for a keyword. But notice the restrictions associated with the keywords below the dashed lines.

Keyword	Function
KEY	Prints this keyword list
TERSE	Set terse mode for minimal prompting
WORDY	Set wordy mode for full prompting
LITTER	Determine load and depth of litter fuels
GRASS	Determine load and depth of grass fuels
SHRUB	Determine load and depth of shrub fuels
SLASH	Determine load and depth of slash fuels
COMP	Display values currently assigned to each of the above four fuel components
FILE	Access fuel model file
RENUMBER	Renumber the fuel model
QUIT	Quit session
RESTART	Start program at beginning again
----------	----------
SURF	Determine surface-to-volume ratios (at least one of the keywords LITTER, GRASS, SHRUB, or SLASH must be used first to assign some fuel loads)
HEAT	Determine heat content (keyword SURF must be used before this keyword)
MODEL	Display tabulation of completed fuel model (keywords SURF and HEAT must be used before this keyword)

Figure 4 reemphasizes the limitations associated with the keywords below the dashed line and also illustrates the general flow of the program. Loads and depth must be defined for at least one of the four fuel components before surface-to-volume (S/V) ratios can be assigned. The S/V ratios must be assigned before heat contents of the fuel components are entered, because S/V ratios are used to calculate a single, weighted heat content for the completed fuel model. Surface-to-volume ratios and heat contents must be **reentered** if a keyword for a fuel model component--LITTER, GRASS, SHRUBS, or SLASH--is used, because you may have modified one or more fuel components.

The program will not accept the keyword "MODEL" until all user-controlled fuel model parameters have been defined, or adjusted if the fuel model has been changed. The fuel model should be added to the file only after you judge that reasonable values have been assigned to all the fuel model parameters under your control. This is best done by looking at the listing obtained from keyword "MODEL". Use of keyword "FILE" will provide an opportunity to save the fuel model on disk. After saving a fuel model, you may either "QUIT" to exit from NEWMDL, or "RESTART" to begin constructing another fuel model. The procedure for accessing any fuel model to test and adjust its fire behavior characteristics is given in the section for operating program TSTMDL.

You should not be able to "crash" the NEWMDL program, so feel free to experiment with it. Appropriate messages are presented and correct actions suggested whenever improper procedures are attempted.

We strongly recommend that you become familiar with the operation and capabilities of NEWMDL before collecting any fuels data in the field. While learning how to construct fuel models, the accuracy of your answers to the questions posed by NEWMDL is much less important than gaining insight into the relationships between the program and the field procedures.

PROGRAM NEWMDL

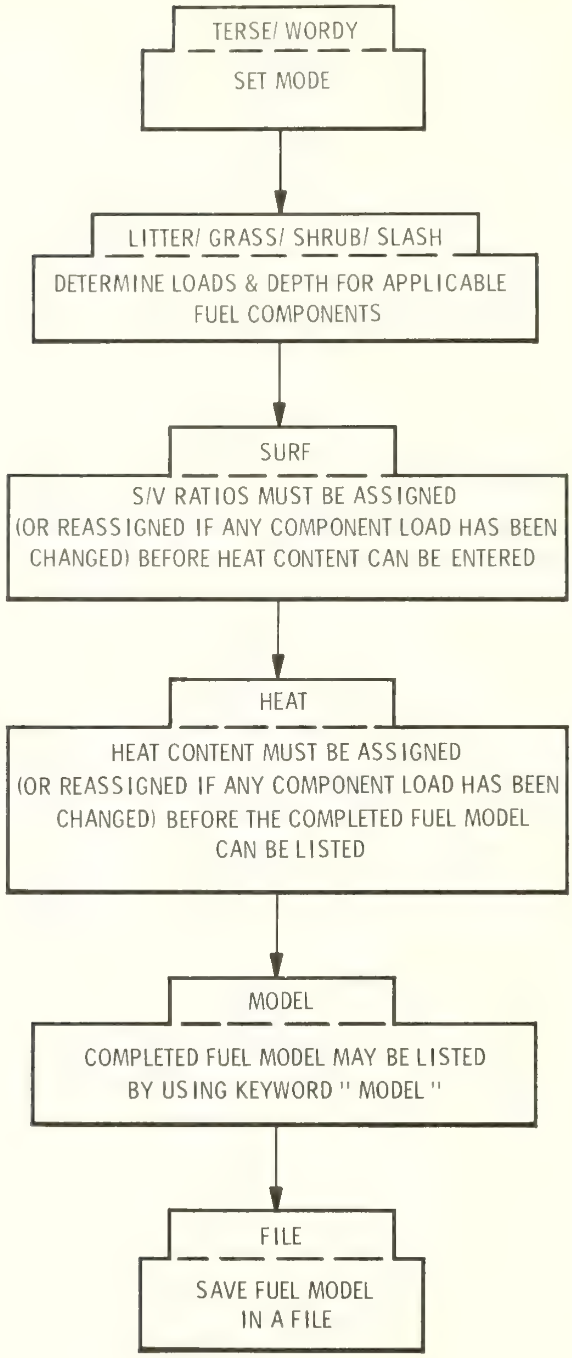

Figure 4.--General flow of program NEWMDL. The general procedure in using the NEWMDL program is to establish fuel load, assign surface-area-to-volume ratios and heat contents, list the model for reference, and save it in a fuel file.

FIELD PROCEDURES

General Data Collection Concept

When building a fuel model the task is more one of describing vegetation as a fuel complex rather than precisely measuring its biomass, although the two are related.

When considering how a particular vegetation type might burn, remember the following limitations of the fire behavior model that will use the fuels data.

1. The fire is assumed to be a line fire burning steadily in **surface** fuels.
2. The fire model is intended to predict fire behavior produced by fine fuels at the perimeter of the fire, usually the fire front.
3. The fire model works best in uniform, continuous fuels such as grass, long-needle pine litter, uniform brushfields, and continuous logging slash.

These limitations have important implications regarding how to view vegetation as a forest or range fuel. For example, because a surface fire is assumed, it is wrong to include vegetation that is in a separate and distinctly higher canopy level than that near the ground. Consider only vegetation that can influence fires before erratic behavior such as crowning or spotting begins.

The fire model predicts behavior on the fire perimeter, normally at the fire front. Inventory **only** the fine fuel that propagates the fire, that is, dead fuels less than 3 inches in diameter and live fuels of less than 1/4-inch diameter. This is often much less than the **total** fuel load per acre. Ignore fuels that burn long after the fire front has passed. These include deep duff, stumps, large logs, and so on.

The assumption of uniform and continuous fuel means that the fire model will calculate fire behavior as though the fuel components in the model were mixed and distributed uniformly throughout the specified depth.

These are reasonable assumptions when nearly all the fuel is represented by just one component, such as a field of grass or a relatively continuous litter layer. The assumptions still hold even when the fuel complex is composed of more than one component--grass, litter, shrub, or slash--if the components are fairly well mixed. When the data for a mixed fuel complex are entered in NEWMDL it will produce a representative fuel model for the mixture.

But if the fuel components occur in separated patches, and the fire will burn from one to another and back again, consider building separate fuel models. Then the two-fuel-model concept available in BURN can be used to predict rate of spread for this situation.

The fact that the assumptions and limitations do not always match reality accounts in part for differences between predicted and observed fire behavior. Nevertheless, a properly developed and tested fuel model can be used with the fire model to produce surprisingly accurate fire potential estimates.

Perhaps the greatest difficulty in constructing a site-specific fuel model is clearly defining the fuel complex it represents. The infinite variability produced by changes in fuel composition, quantity, depth, continuity, and so on, make it imperative that even site-specific fuel models must represent a rather broad range of conditions. Thus, although the first step in constructing a site-specific fuel model may be to obtain field data, at least the following points should be carefully considered in the planning phase:

1. To what general vegetation type will the model apply? Fire should be a recurring problem in this vegetation type, and the vegetation must be readily identifiable and sufficiently abundant to justify the need for a separate fuel model.
2. Should the model be dynamic or static? Dynamic models are needed only if the model is to be used throughout the growing and curing season.

3. Should the two-fuel-model concept be considered?

4. What are the intended uses of the model? This can dictate how accurate the data must be.

5. What is the range of fuel conditions to which the fuel model will apply? Can it be used in similar fuels in other areas? How will it be described so others will know its intended application?

These and other questions arising in your fire management operations will be difficult to answer, but considering such questions in advance is helpful both in the initial collection of field data and in later attempts to apply the model to new situations.

NEWMDL is designed to accept fuel data from a variety of sources. This is not necessarily simpler than a single process, but it does allow the user to utilize data on hand or design field collection procedures to match the needs of the intended application.

If you have discarded the idea of choosing one of the standard 13 models or modifying one of them, you must now select one of the following sources of data:

- utilize inventory data already collected
- collect new inventory data
- use photo series
- use new procedures offered here
- use knowledge about fuels gained from experience
- combination of the above.

The inventory procedures by Brown (1974) are designed to measure fuel load and depth by size class for naturally fallen debris and logging slash. In a later handbook, Brown and others (1982) give more complete procedures for inventorying surface fuels in the interior West. The restriction of their methods to the interior West is necessitated by relating shrub and conifer reproduction measurements to previously measured characteristics of specific species. Their procedures provide estimates of fuel load by size class for duff, litter, grasses and herbs, shrubs, fallen debris, and conifer reproduction. Both living and dead loads are included, but depth of shrubs and duff (not used here) is the only depth tallied.

An ever-expanding photo series is being developed for describing and classifying fuels. Each photographic scene of a fuel complex includes a description of the fuel, a fire potential rating, and data about fuel load by size class.

Fuel inventory procedures and photo series provide data primarily about fuel load. In some cases depth is included, but not always. Brown and others (1982) discuss the difficulty of measuring depth. To construct a fuel model, however, a depth must be provided along with load. The bulk density determined by these two factors is a primary variable needed to drive the fire model (Rothermel 1972). The new procedures presented here overcome this problem by allowing the user to determine a depth that can be used with inventoried loads. The new procedures may also be used to infer fuel loads from estimated fuel depths if inventory data are not available or if the assessment does not warrant the time for inventory.

Figure 2 illustrates the heart of the new procedures, which rely upon the fact that if the bulk density of a fuel component can be estimated, then its load can be calculated using a measurement of the depth, or the depth can be determined from a load measurement. (Bulk density is the fuel load [lb/ft^2] divided by the depth [feet].) Note that in figure 2, the bulk densities are the inverse of the slopes of the lines. There is, of course, scatter about these lines for different fuels. The specific field procedures in the next section allow you to choose a bulk density most appropriate for grass or shrub data. Figure 2 illustrates relationships used within the program in greater detail, and is used to define the load/depth relationships needed.

Data forms described in the next section have been designed to record the data needed to develop a fuel model. They will accommodate data obtained by any of the methods described above. As you work with the forms and procedures, you will find that only part of the data can be obtained from the field; other data regarding particle size and heat content must be provided after prompting by the computer.

Some fuel factors essential to the fire model are held constant because they either have a small effect over their naturally occurring range or would be very difficult for the user to determine.

These are:

Fuel factor	Assumed value
Particle density	32 lb/ft²
Total mineral content*	0.0555
Effective mineral content*	0.010
10-h surface-to-volume ratio	109
100-h surface-to-volume ratio	30

*Fraction of dry weight.

SPECIFIC FIELD PROCEDURES

Reconnaissance

The first step is to conduct a field reconnaissance to obtain a general impression of the fuels to be modeled. A fire that covers a significant area will often be influenced by considerable fuel variability. Try to develop an impression of the "typical" situation by looking at the vegetation in broad terms. During your reconnaissance, consider the following questions about the fuel:

1. Which fuel components--litter, grass, shrubs, and slash--are present in significant quantity?
2. How continuous are the various fuel components?
3. What fuel stratum is most likely to carry fire?
4. Are there large variations in the amount of one or more fuel components?
5. What proportion of the fuel is in the 1-h, 10-h, 100-h, live herbaceous, and live woody categories?
6. How many grass and shrub types must be dealt with?
7. Which bulk density photos best represent the bulk densities of the important grasses and shrubs in the area?
8. What is a representative depth of the grasses, shrubs, litter, or slash in the area?
9. Are the fuels sufficiently intermixed that they can be represented by a single model, or do they occur in independent "patches" that may require use of the two-fuel-model concept?

Field measurements are time consuming and expensive; therefore the new procedures described here have been made as simple as possible. The equipment needed is limited to data forms, a tape measure, a grass clipper, and a photo series, if applicable.

Data Forms

A separate data form is provided for each fuel component--grass, shrubs, litter, and slash. These four forms are for entering data on a single size of 1-h fuels--that is, the familiar three-dead-class, two-live-class fuel model. Each form is divided into two sections: one for summarizing existing inventory data that include both fuel load and depth ("previously inventoried fuel data"), and the other for recording new observations or inventory data that do not contain both load and depth ("new fuel data"). If you have complete information for **either** portion, you will be able to answer all the questions NEWMDL will ask. Depth may not be available from your existing fuels data. In that case you can use the new fuel data portion of the form by supplying the additional required information. Note that this

gives you the option of entering **either** load or depth. Enter load and let NEWMDL calculate a depth for you, but be sure to check it for reasonableness. You will also have to enter percentages of loads in the various size classes rather than the actual values.

A fifth form is for entering data on two sizes of 1-h fuels. Such data have to come from either detailed field measurements or from supplemental computed programs that analyze or predict debris.

Individual Data Forms

GRASS FUEL DATA ENTRY FORM

I. Previously Inventoried Fuel Data

A. Model type (1 - 2) ______

1. Dynamic
2. Static

B. Total grass load (0-30 tons/acre) ______

C. Depth (0-10 ft) ______

D. For dynamic models enter maximum percentage that can be live (0-100%) ______

E. For static models enter current percentage live (0-100%) ______

F. Percentage of area covered by grass (0-100%) ______

II. New Fuel Data

A. Model type (1 - 2) ______

1. Dynamic
2. Static

B. Grass type (1 - 4) ______

1. Fine--e.g., cheatgrass
2. Medium--e.g., rough fescue
3. Coarse--e.g., fountaingrass
4. Very coarse--e.g., sawgrass

C. Bulk density class (1 - 6) (refer to photos in user's manual) ______

D. Total grass load (0-30 tons/acre) ______

or

E. Grass depth (0-10 ft) ______

F. For dynamic models enter maximum percentage that can be live (0-100%) ______

G. For static models enter current percentage live (0-100%) ______

H. Percentage of area covered by grass (0-100%) ______

SHRUB FUEL DATA ENTRY FORM

I. Previously Inventoried Fuel Data

A. Loads (tons/acre)

1. 1-HR (0-30) ____________

2. 10-HR (0-30) ____________

3. 100-HR (0-30) ____________

4. Leaves and live twigs (0-30) ____________

B. Depth (0-10 ft) ____________

C. Percentage of area covered by shrubs (0-100%) ____________

D. Oils and waxes (circle one) Yes No

II. New Fuel Data

A. Shrub type (1-5) ____________

1. Fine stems, thin leaves--e.g., huckleberry
2. Medium stems, thin leaves--e.g., ninebark
3. Medium stems, thick leaves--e.g., ceanothus
4. Densely packed fine stems and leaves--e.g., chamise
5. Thick stems and leaves--e.g., manzanita

B. Bulk density class (1-6) (refer to photos in user's manual) ____________

C. Total shrub load (0-80 tons/acre) ____________

or

D. Shrub depth (0-10 ft) ____________

E. Percentage of total shrub load in each size class. Enter as whole percentile (must total 100%)

1. 1-HR (0-1/4 inch) ____________

2. 10-HR (1/4-1 inch) ____________

3. 100-HR (1-3 inches) ____________

4. Live leaves and twigs (0-1/4 inch) ____________

F. Percentage of area covered by shrubs (0-100%) ____________

G. Oils and waxes (circle one) Yes No

LITTER FUEL DATA ENTRY FORM

I. Previously Inventoried Fuel Data

A. Loads (tons/acre)

1. 1-HR (0-30) ______________

2. 10-HR (0-30) ______________

3. 100-HR (0-30) ______________

B. Depth (0-5 ft) (ft = cm ÷ 30.48) ______________

C. Area coverage (0-100%) ______________

II. New Fuel Data

A. Litter source (1 - 3) ______________

1. Conifers
2. Hardwoods
3. Both, but at least 30% of lesser type

B. Needle length if conifers or both (1 - 2) ______________

1. Medium/long--e.g., lodgepole or ponderosa pine
2. Short--e.g., Douglas-fir

C. Litter compactness (1 - 3) ______________

1. Loose (freshly fallen)
2. Normal
3. Compact (older compressed litter)

D. Total litter load (0-100 tons/acre) ______________

or

E. Litter depth (0-5 ft) (ft = cm ÷ 30.48) ______________

F. Percentage of total litter load in each size class. Enter as whole percentile (must total 100%)

1. 1-HR (0-1/4 inch) ______________

2. 10-HR (1/4-1 inch) ______________

3. 100-HR (1-3 inches) ______________

G. Percentage of area covered by litter (0-100%) ______________

SLASH FUEL DATA ENTRY FORM

I. Previously Inventoried Fuel Data

A. Loads (tons/acre)

1. 1-HR (0-30) ____________

2. 10-HR (0-30) ____________

3. 100-HR (0-30) ____________

B. Depth (0-10 ft) ____________

C. Area coverage (0-100%) ____________

II. New Fuel Data

A. Logging method (1 - 3) ____________

1. Commercial timber cut, high lead skidding
2. Commercial timber cut, ground lead skidding
3. Precommercial thinning

B. Age (0-5 yr) ____________

C. Total component load (0.01-100 tons/acre) ____________

D. Total 10-h load (0.01-30 tons/acre) ____________

Major species	Crown class (1-Dom) (2-Int)	Ave d.b.h.	Species % foliage retention	% by species if C or D	E Species 10-HR load per acre	F Species intercepts per foot

G. Average percentage twig retention, all species ____________

H. Area coverage (0-100%) ____________

MULTIPLE 1-HOUR DATA ENTRY FORM

I. LITTER COMPONENT

Loads (0-30 tons per acre)		S/V ratios (800-3,500 ft^2/ft^3)
1-HR	__________	____________________
1-HR	__________	____________________
10-HR	__________	
100-HR	__________	
Depth (0-5 ft)	__________	
Area coverage (%)	__________	

II. SLASH COMPONENT

Loads (0-30 tons per acre)		S/V ratios (800-3,500 ft^2/ft^3)
1-HR	__________	____________________
1-HR	__________	____________________
10-HR	__________	
100-HR	__________	
Depth (0-10 ft)	__________	
Area coverage (%)	__________	

III. SHRUB COMPONENT

Loads (0-30 tons per acre)		S/V ratios (800-3,500 ft^2/ft^3)
1-HR	__________	____________________
1-HR	__________	____________________
10-HR	__________	
100-HR	__________	
Live woody	__________	
Depth (0-10 ft)	__________	
Area coverage (%)	__________	
Waxes or oils (yes/no)	__________	

IV. GRASS COMPONENT

Loads (0-30 tons per acre)		S/V ratios (800-3,500 ft^2/ft^3)
1-HR	__________	____________________
1-HR	__________	____________________
10-HR	__________	
Live herbaceous	__________	
Depth (0-10 ft)	__________	
Area covered (%)	__________	
Model type (dynamic/static)	__________	

COMMON DATA ITEMS

Four items that occur in several places on the data forms will be defined prior to subsequent use in the detailed explanation of data entries for each fuel component.

Total component load.--This is the total load for an individual fuel component (grass, shrub, litter, or slash). It can be any combination of 1-, 10-, and 100-h dead fuels, live herbaceous material, and the leaves and 1/4-inch or smaller twigs of live shrubs. This fuel generally occurs within 6 feet of the F layer surface. Record in tons per acre.

Individual live and dead loads.--These loads are most commonly available from existing inventory data. Record in tons per acre for each of the following loads that should be included in the fuel model:

Dead fuels: 1-h (less than 1/4-inch diameter)
10-h (1/4- to 1-inch diameter)
100-h (1- to 3-inch diameter)

Live fuels: Leaves and live twigs less than 1/4-inch diameter.
Enter zero for those that are inappropriate.

Percent of the loads in individual classes.--When using the "New Fuel Data" portion of the shrub and litter forms, estimate as necessary the percentage of the total load in the 1-h, 10-h, 100-h, and/or live fuel classes. These percentages are used to break the total load into individual live and dead loads. Record the percentages of live and dead fuels to the nearest whole percentile. The percentages must sum to 100 for each component.

Depth.--Record the average depth of the fuel model component in feet. If the litter component is shallow, it may be measured in centimeters, then converted to feet. Review the definition of depth in the section "General Field Observation Concepts" for "Grass and Shrubs" if there is any question about what depth is. See also figures 5 and 6. Experience has shown that 70 percent of the maximum depth gives a reasonable estimate of depth for grass, shrubs, and slash, while maximum depth is more appropriate for fallen litter fuels that are lying horizontally.

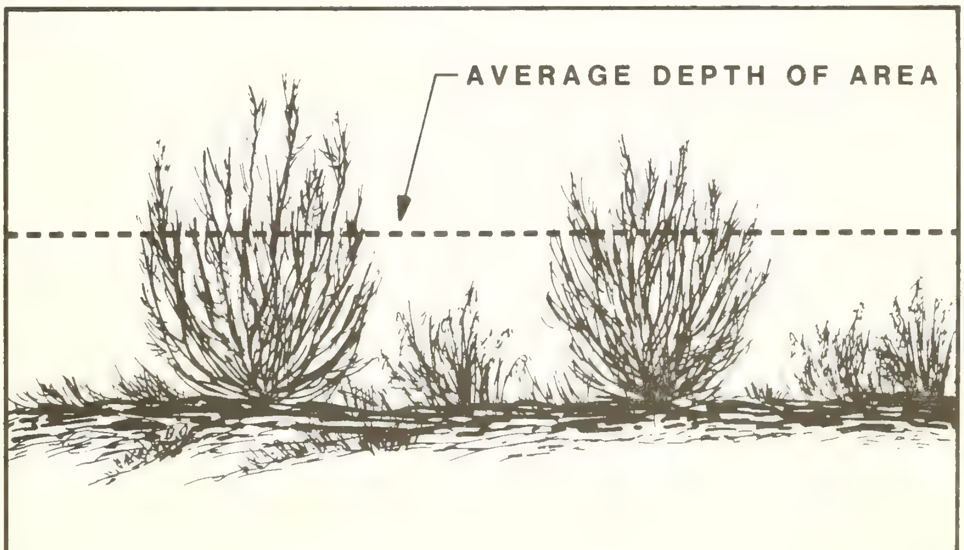

Figure 5.--Concept of grass and shrub depths. Average grass or shrub depth is about 70 percent of the maximum leaf or stalk height. It can be visualized as the average height of a pliable sheet draped over the fuel particles.

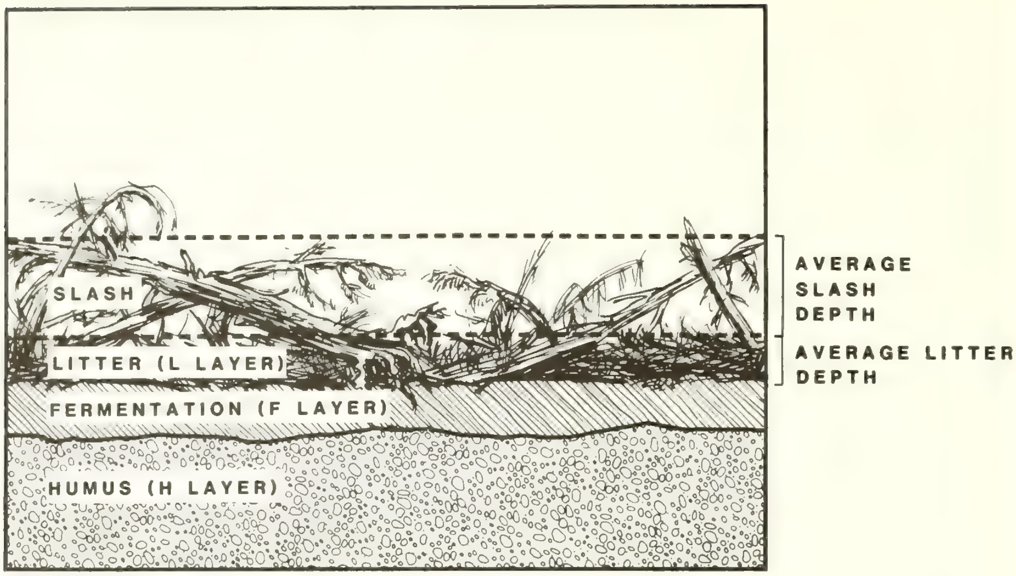

Figure 6.--Concept of slash and litter depth. Litter depth is the vertical distance from the top of the F layer to the general upper surface of the L layer. Slash depth is about 70 percent of the distance from the top of the natural litter layer to the average high intercept. It can be visualized as the average depth of a pliable sheet draped over the fuel particles.

Percentage of the area covered by each fuel component.--Initial fuel load estimates are based on the assumption that 100 percent of the area is covered by the fuel component in question. If your inventory procedure was to sample the entire area, both where fuel existed and where it did not exist, enter 100 for the percentage of area covered. Then your inventoried load will not be reduced. If you used the inventory procedure presented here for collecting "new" fuel data, enter your estimate of the percentage of the area actually covered by each fuel component. Then fuel loads will be reduced from the assumed 100 percent coverage to actual coverage.

Estimating bulk density classes for grasses and shrubs.--Appendix A provides photo sets to help visualize bulk densities for different grass and shrub types, ranging from fine to very coarse.

First select the photo set that best represents the morphology of the grass or shrub type that will most effectively carry the fire. Then select the photo within that type that best represents its bulk density. If the grasses or shrubs occur in clumps, select a photo that best represents the bulk density of a typical clump, rather than trying to estimate the average bulk density that would exist if all the vegetation in the clumps were spread evenly over the entire area.

Once the bulk density for grasses and shrubs (or both) has been estimated, then either their average loads or depths must be determined. Grass and shrub loads per acre can be estimated by clipping and weighing 3-inch diameter and smaller material from sample plots of known size, ovendrying it, weighing it, and expanding the average sample plot load to a per-acre basis. In this process it must be assumed that the grasses and shrubs cover 100 percent of the area, even if that is not true. NEWMDL reduces these loads for the percentage of the area you state is actually covered by grasses or shrubs.

Estimating the grass or shrub load from its depth is a much faster procedure. The depth of any fuel component is the vertical distance from the bottom of the fuel component layer to the appropriate height at which the bulk density begins to rapidly decrease; or alternatively

about 70 percent of the average maximum leaf or stalk height. Figure 5 illustrates this definition for grass and shrub components. Depth must be estimated with the assumption that the shrub or grass type under consideration covers 100 percent of the area. From that, NEWMDL will first estimate the load per acre based on 100 percent area coverage, then reduce that load for actual area coverage.

Estimating load and depth for litter and slash.--Bulk density photos for litter are impractical; therefore the bulk densities are based on litter source (hardwoods, conifers, or both), conifer needle length (long, medium, or short), and litter compactness (loose, normal, or compact). These data are used by NEWMDL, along with a depth value, to determine litter load. Litter depth is defined as the vertical distance from the top of the F layer to the general upper surface of the L layer. Scattered protruding fuel particles are to be ignored. Figure 6 illustrates the definition of depth for slash and litter.

By far the most research has been done on slash, so the relationships developed in these studies have been used to simplify field observations for estimating slash loads and depths. The required information includes logging method, slash age, and one of several expressions of slash load. If estimating slash load is difficult, the data sheets which accompany photo series often provide an excellent source of information. These data are most conveniently recorded as "previously inventoried fuel data." A partial list of available photo series is included in the "References" section.

A note of caution is advised when using photo series. The 1-h load given on the data sheet will probably not account for needles still retained on slash. This is because the standard fuel inventory technique used to develop these data (Brown 1974) does not include measurements on needle loads. Brown recognizes this and has provided multiplying ratios to calculate needle quantity based on estimated branch wood weight. These ratios are presented in his appendix III for several species of western conifers. Modification of the 1-h load presented in a photo series is appropriate for "red needle" slash.

Alternatively, fuel loads for litter or slash may be determined directly using inventory techniques described by Brown (1974). His publication provides excellent documentation and detailed instructions that need not be repeated here. NEWMDL does not require an inventory as described by Brown, but use of his procedures will provide all the load and depth information required for litter and slash loads. Again, remember to account for needle load when inventorying "red" slash. If you have never measured fuels, some practice will be helpful in understanding and utilizing the methods described here.

SPECIFIC DATA

Specific instructions for completing the data forms for individual fuel components follow.

Grass Component

I. Previously inventoried fuel data

   A. Model type - Record whether the model is to be dynamic or static.

   B. Total grass load - Record total grass load (live and dead) in tons per acre.

   C. Depth - Record adjusted grass depth in feet.

   D. Maximum percentage that can be live - For dynamic fuel models, indicate the greatest proportion of the total grass load that is live at any time during the year, regardless of how green the grass may be at the present time. Accumulation of dead grass from previous seasons will generally keep this number below 50 percent. Leave blank if you are building a static fuel model.

E. Current percentage live - For static fuel models enter the proportion of the grass, by volume, that is live at the time of year for which the model is being designed. It can be estimated by clipping a few pounds of grass, separating all the live material into one pile and all dead material into a number of piles equal in size to the pile of live material. Then the percentage value to enter is:

$$\frac{100}{\text{(total number of piles)}}$$

Make no entry if you are building a dynamic model.

F. Area coverage - Record percentage of area covered by grass.

II. New fuel data

A. Model type - Record "dynamic" or "static" as explained under I-A above.

B. Grass type - Compare each page of grass type (1, 2, 3, and 4) photos with your field situation. Record the number of the grass type which is most similar morphologically. The purpose of this step is to just select a general grass type category.

C. Bulk density class - The bulk density is defined by matching bulk density photos of the appropriate grass type with your field observations. Record the density class number (1-6).

D. Total grass load - Record if available from a "clip and weigh" inventory, otherwise leave blank.

E. Grass depth - Record adjusted depth in feet. That is, 70 percent of maximum depth. See figure 5.

F. Maximum percentage live - See I-E above.

G. Current percentage live - See I-F above.

H. Area coverage - Record percentage of the area covered by grass.

Shrub Component

I. Previously inventoried fuel data

A. 1-, 10-, and 100-h dead fuel loads, leaf and live twig loads - Record the load for each of these fuel categories that should be included in the fuel model. Enter zero for those that are inappropriate.

B. Depth - Record the adjusted shrub depth in feet.

C. Area coverage - Record percentage of the area covered by shrubs.

D. Oils and waxes - Some shrubs contain oils and waxes that significantly increase the contribution of the live foliage to the fire intensity and also increase the moisture content at which these fuels will burn. Record whether such material is or is not present in the shrubs.

II. New fuel data

A. Shrub type - Compare each page of shrub type (1, 2, 3, 4, and 5) photos with your field situation. Circle the number of the shrub type which is most similar morphologically.

B. Bulk density - Select by matching bulk density photos of the appropriate shrub type with the field situation. Record the bulk density class number (1-6).

C. Total shrub load - Record total shrub load in tons per acre if available from a clip-and-weigh inventory, otherwise leave blank.

D. Depth - Record shrub depth in feet.

E. Percentage of shrub load in each size class - Estimate to nearest whole percentile.

F. Area coverage - Record percentage of area covered by shrubs.

G. Oils and waxes - Review I-D for shrubs if necessary; then record yes or no.

Litter Component

I. Previously inventoried fuel data

A. 1-, 10-, and 100-h loads - Record in tons per acre for each of those fuel categories that should be included in the fuel model. Enter zero for those that are inappropriate.

B. Depth - Record average litter depth in feet. If the litter is shallow it may be measured in centimeters, then converted to feet by dividing by 30.48.

C. Area coverage - Enter percentage of area covered by litter.

II. New fuel data

A. Litter source - Record whether the litter results from hardwoods, conifers, or both.

B. Needle length - Needle length affects the bulk density of conifer litter, with medium- to long-needle species such as lodgepole or ponderosa pine producing a litter bed having a lower bulk density than short-needle conifers such as larch or Douglas-fir. Record as medium/long or as short.

C. Litter compactness - NEWMDL will use different bulk densities for loose, normal, or compact litter. Hardwood litter particularly is most likely to be loose or fluffy when it first falls, but compact after it has been on the ground for at least one winter.

D. Total litter load - Record total litter load in tons per acre if available from an inventory. Skip this entry if it is unknown.

E. Depth - Record litter depth in feet. If the litter is shallow it may be measured in centimeters, then converted to feet by dividing by 30.48.

F. Percentage of litter load in each size class - Estimate to nearest whole percentile.

G. Area coverage - Record percentage of area covered by litter fuels.

Slash Component

I. Previously inventoried fuel data. Data obtained by comparing photo series with the field situation should be entered here.

A. 1-, 10-, and 100-h loads - Record in tons per acre for each of those fuel categories to be included in the fuel model. Enter zero for those that are not appropriate.

B. Depth - Record slash depth in feet.

C. Area coverage - Record percentage of the area covered by slash.

II. New fuel data

A. Logging method - Record as 1, 2, or 3 to define the slash origin as follows:

1. Commercial timber cut, high lead skidding
2. Commercial timber cut, ground lead skidding
3. Precommercial thinning

B. Age - Record slash age as number of winters it has existed.

Slash load data can be recorded in the most convenient form as expressed by C, D, E, or F below. In any case, record the **major species** comprising the slash, the **crown class** code (dominant [1] or intermediate [2]), and the **average d.b.h.** of each species. You may record the percentage of foliage retention by species if you would rather use your own data than have the program make these estimates for you.

C. Total slash load - If the total slash load is available, enter as tons per acre; otherwise leave blank. If entered, record percentage of slash contributed by each species.

D. Total 10-h load - If the total 10-h load is known, enter as tons per acre; otherwise leave blank. If entered, record percentage of the slash contributed by each species.

E. Species 10-h load per acre - Record the major species comprising the slash and the 10-h load per acre for each species. Enter as tons per acre. Entry of percentage slash by species is not required.

F. Species intercepts per foot - Record the species name and the number of 10-h intercepts per foot for each major species comprising the slash. Entry of percentage slash by species is not required.

G. Average twig retention, all species. Enter the percentage of twigs less than 1/4-inch diameter still retained on the slash. Estimate an average value for all the slash, rather than for each species.

H. Area coverage - Enter percentage of area covered by slash.

Multiple 1-Hour Fuels

Although the familiar 3-dead-class, 2-live-class fuel model should be adequate for most fuel modeling jobs, there may be situations where two distinctly different sizes of 1-h fuels exist. One example might be dead leaves and twigs on frost- or drought-killed shrubs; another example is red coniferous slash such as ponderosa pine where the needles have a much smaller average size than the twigs.

The NEWMDL program contains a section that will accept data on the load and surface-to-volume ratios for two sizes of 1-h fuels plus the 10-h, 100-h, and live fuels. This is called a 4-dead-class, 2-live-class fuel model. You are given the option of selecting this capability early in the NEWMDL program when you are asked whether you want to build a model with one or two sizes of fine fuels. Select the option for two sizes of fine fuels if you have the data for the "Multiple 1-Hour Data Entry Form." Appropriate data can be obtained from option 2 of the DEBMOD program (Puckett and Johnson 1979), or from a fuels inventory you conduct in the field to get the data. This section of NEWMDL requires that you have the data on hand for direct entry. The program will not give any tutorial assistance on values to enter.

On completion of data entry, the program will change your 4-dead-class, 2-live-class model to a 3-dead-class, 2-live-class model so that it will be compatible with the rest of the BEHAVE system and the TI-59. The 1-h load and fuel bed depth must be altered in this process to preserve the fire behavior characteristics of the model, so do not be concerned about that. The resultant 3-dead-class, 2-live-class model should be tested with the TSTMDL program where you can make any necessary adjustments.

The "Multiple 1-Hour Data Entry Form" is simple enough that detailed explanation should not be necessary. Just record and enter the data for those components that contribute significantly to the fuel model. Remember, this section of the program expects direct entry of your data. It will not suggest values to enter.

Estimating surface-area-to-volume ratios.--When using NEWMDL to enter your data, you will be asked for surface-area-to-volume (S/V) estimates. The following tabulation presents three broad ranges of S/V ratios for grass, broadleaf, and coniferous plants. Although the specific plant(s) you are concerned with may not be listed, you should be able to find a plant similar enough to select among the three S/V ratio ranges. The midpoint of the appropriate range would be a good initial value. You may adjust this value later when using the TSTMDL program to modify your initial fuel model.

Estimating heat content.--Heat content estimates are requested when you enter your fuel model data into NEWMDL. Guidelines are provided by the program and will not be repeated here.

Surface-Area-to-Volume Ratio Ranges for Various Plants

500-1,500 ft^2/ft^3	1,500-2,500 ft^2/ft^3	More than 2,500 ft^2/ft^3
	Grasses	
Jamaica sawgrass (*Mariscus jamaicensis*)	Fountaingrass (*Pennisetum setaceum*)	Medusahead (*Taeniatherum asperum*)
	Molassesgrass (*Melinis minutiflora*)	Cheatgrass (*Bromus tectorum*)
		Pinegrass (*Calamagrostis rubescens*)
		Idaho fescue (*Festuca idahoensis*)
		Crested wheatgrass (*Agropyron spicatum*)
		Broomsedge (*Andropogon virginicus*)
	Broadleaved plants	
Yellow beadlily (*Clintonia borealis*)	Palmetto (*Sabal* spp.)	Wild sarsaparilla (*Aralia nudicaulis*)
Sonoma manzanita (*Arctostaphylos densiflora*)	Common pearleverlasting (*Anaphalis margaritacea*)	Bunchberry dogwood (*Cornus canadensis*)
	Gallberry	Brackenfern (*Pteridium aquilinum*)
	Spreading dogbane (*Apocynum androsaemifolium*)	Serviceberry (*Amelanchier* spp.)
	Bigleaf aster (*Aster macrophyllus*)	Roundleaf dogwood (*Cornus rugosa*)
	Marsh peavine (*Lathyrus palustris*)	Willow (*Salix* spp.)
	Interrupted-fern (*Osmunda claytoniana*)	Showy mountainash (*Sorbus decora*)
	Eucalyptus (*Eucalyptus obliqua*)	Ninebark (*Physocarpus malvaceus*)
		Oceanspray (*Holodiscus discolor*)
		Mountain alder (*Alnus sinuata*)
		Menziesia (*Menziesia ferruginea*)
		Snowberry (*Symphoricarpos albus*)
		Blue huckleberry (*Vaccinium globulare*)
		Quaking aspen (*Populus tremuloides*)
		Red maple (*Acer rubrum*)
		White oak (*Quercus alba*)
		Scrub oak (*Quercus dumosa*)
		Oregon-grape (*Berberis repens*)
	Conifer needles	
Eastern hemlock (*Thuja canadensis*)	Jack pine (*Pinus banksiana*)	Eastern white pine (*Pinus strobus*)
Northern white-cedar (*Thuja occidentalis*)	Balsam fir (*Abies balsamea*)	Western white pine (*Pinus monticola*)
	Ponderosa pine (*Pinus ponderosa*)	Western hemlock (*Tsuga heterophylla*)
	Engelmann spruce (*Picea engelmannii*)	Western larch (*Larix occidentalis*)
	Lodgepole pine (*Pinus contorta*)	
	Douglas-fir (*Pseudotsuga menziesii*)	
	Grand fir (*Abies grandis*)	
	Loblolly pine (*Pinus taeda*)	
	Western redcedar (*Thuja plicata*)	

PROGRAM TSTMDL

General Concept

The purposes of TSTMDL are to: (1) provide a means to examine the fire behavior characteristics of the initial fuel model under a variety of environmental conditions, and (2) provide a convenient method to examine the effect on fire behavior when individual fuel model parameters are modified. Although the NEWMDL and TSTMDL programs systematize fuel modeling, it is far from a mechanical process that produces incontrovertible results. **It is extremely important to test every fuel model for the broadest range of environmental conditions to which it may be applied.** Otherwise you may find, for example, that a fuel model that works well for low fuel moistures or windspeeds produces unrealistic fire behavior for high moistures or windspeeds. These tests can and should be performed with the TSTMDL program, but you are also encouraged to test any new model with the BURN program to verify that it will not produce spurious results when used operationally.

The initial verification of a fuel model rests upon your judgment of whether the rate of spread, flame length, and other values are reasonable for a range of environmental conditions. Field verification can only be attained by using the model and comparing its predictions with actual observations. Rothermel and Rinehart (1983) define techniques for observing fire behavior that can be used to assess whether your fuel model produces reasonable values.

TSTMDL has both a "normal" and a "technical" version. The program defaults to the normal version when you first begin. The normal version is for those situations in which a model can be built rather easily, without a need for extensive examination. It provides three graphs and a table. The graphs are: (1) rate of spread versus midflame windspeed, (2) flame length versus midflame windspeed, and (3) the fire characteristics chart (Andrews and Rothermel 1982). Rate of spread and flame length are graphed for either one or three values of 1-h fuel moisture over a midflame windspeed range of 0 to 18 mi/h. This chart enables comparison of your fuel model's behavior characteristics plots to one or two of the 13 NFFL fuel models for currently defined environmental conditions.

The tabular output is identical in both the normal and technical versions. It allows you to assign three values to any environmental parameter, then lists the fuel model and the values calculated for five fire behavior parameters: (1) rate of spread, (2) flame length, (3) reaction intensity, (4) heat per unit area, and (5) fireline intensity.

The technical version provides additional graphic output. It allows you to place any fuel or environmental parameter on the x-axis and examine its affect on any appropriate fire behavior parameter. Thus the technical version provides a great deal of flexibility, and a powerful means to examine the influence of the fuel model parameters on fire behavior calculations. The interactions between the fuel model, fire model, and environmental parameters are exceedingly complex. You will undoubtedly get some mystifying plots, but the educational value of this program lies in understanding them.

Program Structure

The TSTMDL program has three sections, each controlled by keywords. The first section is the "control," which permits task selection and general program control; the second section is the "fuel and environment manipulation" section for changing values of individual parameters, and the third section is the "fuel and environment modification" section, which provides for data entry and listing (fig. 7).

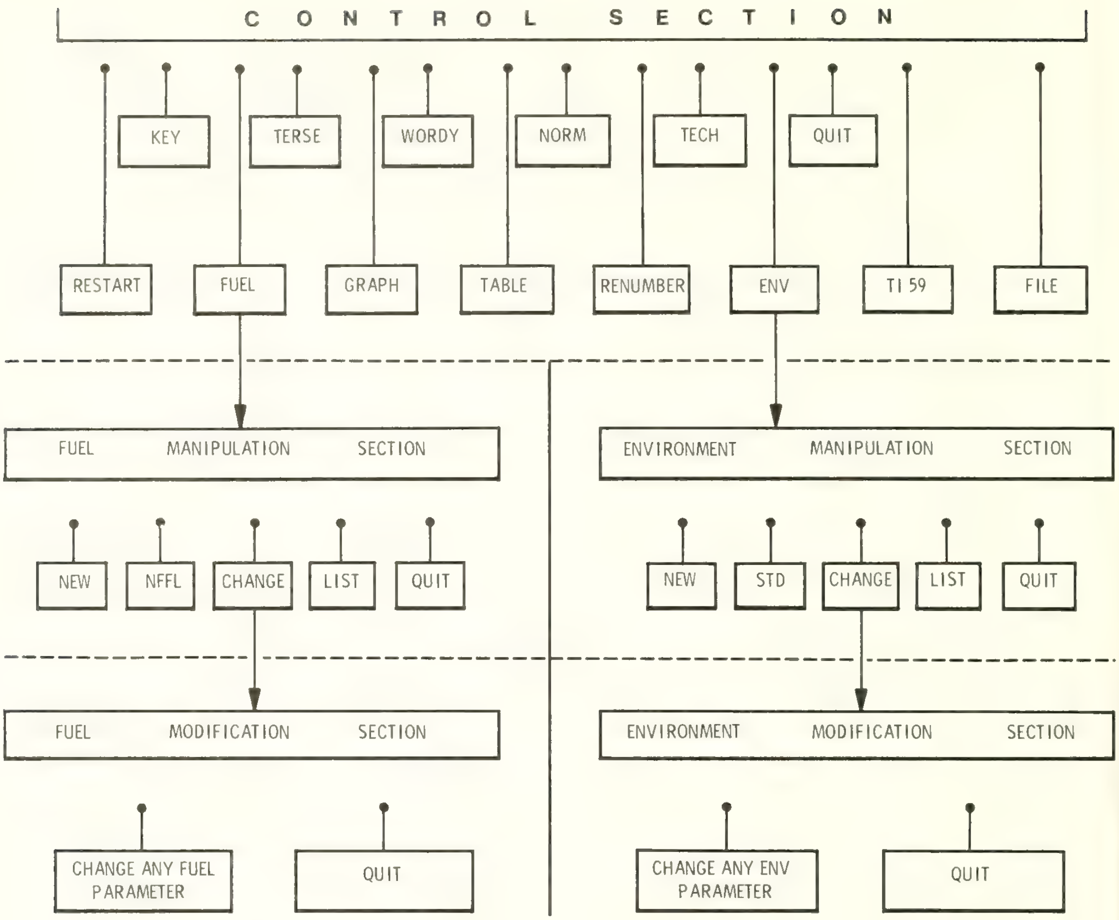

Figure 7.--General flow of program TSTMDL. The TSTMDL program has three sections: control, fuel or environment manipulation, and fuel or environment modification. Keywords associated with each section provide user control.

When you are at the "control" section, you get to the "fuel" or "environment" manipulation section by entering keyword FUEL or ENV, respectively. Then, entry of keyword CHANGE takes you to the third section, the "fuel modification" or "environment modification" section. Each entry of keyword QUIT moves you up one section. Thus you QUIT section three to get to section two and also QUIT section 2 to get back to the "control" section. Entering QUIT from the "control" section terminates operation of the program.

The keyword method of program control permits much flexibility in program operation. For example, whenever prompted for a keyword, you can enter any keyword belonging to the section where you are. Thus program flow does not follow a strict pattern, but allows you to perform tasks defined for each section in any sequence. This capability is symbolized by the dot and short line leading to each keyword. Note that only the keywords FUEL, ENV, CHANGE, and QUIT will move you from one section to another.

A list of keywords and their functions in program control and manipulation of fuels and environmental data is provided in table 1.

Table 2 provides a list of keywords for selecting an environmental variable to which additional values can be temporarily assigned for tabular input, and a list of variables that can be assigned to the X and Y axes when using the technical version's graphics.

Table 1.--TSTMDL keywords and functions

Control Section

KEYWORD	FUNCTION
KEY	Prints this keyword list
TERSE	Set terse mode for minimal prompting
WORDY	Set wordy mode for full prompting
NORM	Implement "normal" version of program
TECH	Implement "technical" version of program
FUEL	Go to "fuel manipulation" section
ENV	Go to "environment manipulation" section
GRAPH	Request graphic output of computed results
TABLE	Request tabular output of computed results
RENUMBER	Renumber fuel model and select dynamic or static
RESTART	Start program at beginning again
FILE	Access the fuel model file
TI59	List fuel model and TI-59 registers
QUIT	Quit this session with TSTMDL

Fuels and Environment Manipulation Section

Fuels		Environment	
KEYWORD	FUNCTION	KEYWORD	FUNCTION
NEW	Enter new fuels data	NEW	Enter new environmental data
NFFL	Enter a fire behavior model	STD	Enter standard environmental data
CHANGE	Go to "fuel modification" section	CHANGE	Go to "environment modification" section
LIST	List fuel model	LIST	List environmental data
QUIT	Go to "control" section	QUIT	Go to "control" section

Fuels and Environment Modification Section

Fuels		Environment	
KEYWORD	FUNCTION	KEYWORD	FUNCTION
	Change the:		Change the:
SA1	1-HR S/V ratio	M1	1-HR fuel moisture
SAH	Herb S/V ratio	M10	10-HR fuel moisture
SAW	Woody S/V ratio	M100	100-HR fuel moisture
DEPTH	Fuel bed depth	MHERB	Live herb moisture
HEAT	Heat content	MWOOD	Live woody moisture
EXTM	Extinction moisture	WIND	Midflame windspeed
L1	1-HR fuel load	SLOPE	Percent slope
L10	10-HR fuel load	QUIT	Go to "environment manipulation" section
L100	100-HR fuel load		
LH	Herbaceous load		
LW	Woody load	KEY	List these keywords
KEY	List these keywords		
QUIT	Go to "fuel manipulation" section		

Table 2.--TSTMDL keywords for tabular and graphic output

Tabular Output Keywords

KEYWORD	FUNCTION
KEY	Print this keyword list
M1	1-HR fuel moisture
M10	10-HR fuel moisture
M100	100-HR fuel moisture
MHERB	Live herb fuel moisture
MWOOD	Live woody fuel moisture
WIND	Midflame windspeed
SLOPE	Slope

Graphic Output Keywords

KEYWORD	MEANING
KEY	Print this keyword list
SA1	1-HR S/V ratio
SAH	Herb S/V ratio
SAW	Woody S/V ratio
L1	1-HR fuel load
L10	10-HR fuel load
L100	100-HR fuel load
LH	Herb fuel load
LW	Woody fuel load
DEPTH	Fuel bed depth
EXTM	Extinction moisture
HEAT	Heat content
M1	1-HR fuel moisture
M10	10-HR fuel moisture
M100	100-HR fuel moisture
MHERB	Herb fuel moisture
MWOOD	Woody fuel moisture
WIND	Midflame windspeed
SLOPE	Percent slope

TSTMDL Technical Version Y-axis Keywords

FLINT	Fireline intensity
RATE	Rate of spread
REAC	Reaction intensity
FLAME	Flame length
H/A	Heat per unit area
PACK	Packing ratio
RSFL	Rate of spread to flame length ratio

Program Operation

The specific procedure for accessing your computer and the TSTMDL program must be obtained from your computer specialist. When you begin, the first message will indicate that you are using the fuel model testing program and ask you to enter your last name. A maximum of 20 characters is allowed. Then you will be asked if you are using a hard copy device such as a printing terminal. The purpose of this question is to indicate whether pauses are necessary in the flow of output, as when a CRT screen is filled.

Your next response will be to indicate whether you want the TERSE mode. Answer "No" unless you are an experienced user.
You will then be asked whether you will be creating a new fuel model or loading a previously built model from your fuel model file. After making this choice you will either be asked to enter a number for your proposed new model or for the previously built model to be selected from the fuel model file. If you are creating a new model you will also be asked to enter a name for the model and whether it is to be "dynamic" or "static."
The next question is whether you want a list of keywords and their functions. Because keywords control the program, this is a good time to list them for reference, or you may decline the list.
If you are using the WORDY version, the next program prompt is a suggestion to enter NORM or TECH to get the version you want. This prompt is not printed in the TERSE version. The NORMAL version is the default, so if this is what you want, keyword NORM does not have to be entered, but doing so will print a message indicating that the NORMAL version is set. You can get the TECHNICAL version only by asking for it.
The next prompt is "CONTROL SECTION. KEYWORD?". Whenever this prompt appears, you can enter any keyword in the control section keyword list, although you will get error messages if the wrong ones are entered first. Such messages will not cause the program to "crash," but return control to the point where you can enter another keyword. The general approach should be to:

1. Define the fuel model. Keyword FILE will give you a chance to get a custom model from the fuel model file. Otherwise keyword FUEL will give you the opportunity to select a fire behavior model, input new fuel model data, change, or list all fuel model data.
2. Define the environmental data. Keyword ENV will allow you to enter, change, or list the environmental data. You can either assign your own values to the environmental parameters, or select one of the "standard" conditions.
3. Define the type of output you want; that is, graphic (keyword GRAPH), or tabular (keyword TABLE). In either case you will be asked a few questions required to set up the graph or table.

After your first time through, in which you set up the fuel and environmental data, you have complete freedom to use the keywords in any order. For example, you can enter keyword FUEL or ENV, change the value of one or more fuel or environmental parameters, then output another graph or table. You can also switch between the TERSE and WORDY modes or the NORMAL and TECHNICAL versions whenever "CONTROL SECTION. KEYWORD?" is printed.

It is not necessary to enter decimal points unless your intention is to enter a decimal fraction. They are not required for integer numbers.
To obtain the list of TI-59 registers and numbers needed to record this fuel model on a magnetic card, enter keyword TI59.
Like NEWMDL, TSTMDL is designed to be a friendly and "difficult to crash" program, so you are encouraged to explore its capabilities until you are completely familiar with its operation.
Remember that although fuel models can be created with the TSTMDL program by entering the data directly, its primary purpose is for testing models initially built with the NEWMDL program.

FUEL MODELING CONCEPTS

Introduction

Interactions between fuel model, topography, and environmental parameters, and the mathematical fire spread model are so numerous and complex that attempting to present all the possible results would be an unreasonable task. Yet a basic understanding of the relationships provides valuable insight to the fuel modeling process. Therefore this section is presented for those who are interested in examining in detail the concepts most important to fuel modeling.

The mathematical fire model developed by Rothermel (1972) and amended by Albini (1976) provides a means to estimate the rate at which a fire will spread through a uniform fuel array that may contain fuel particles of mixed sizes. It is basically a rate of spread model, but it also computes an intensity that can be interpreted into the more familiar fireline intensity and flame length developed by Byram (1959).

The Fire Spread Model

The theoretical basis for the fire spread model was developed by Frandsen (1971). The terms of Frandsen's equation could not be solved analytically, however, so it was necessary to define new terms, reformulate the equation, and design experimental methods to evaluate the individual terms. The final form of the rate of spread equation, derived by Rothermel (1972), which will be examined in depth is:

$$R = \frac{I_r \xi (1 + \phi_w + \phi_s)}{\rho_b \varepsilon Q_{ig}}$$

where

- R is the forward rate of spread of the flaming front, in feet per minute.
- I_r is the reaction intensity--a measure of the energy release rate per unit area of fire front (Btu/ft^2/min).
- ξ ('ksē) is the propagating flux ratio--a measure of the proportion of the reaction intensity that heats adjacent fuel particles to ignition.
- ϕ_w (fē wind) is a dimensionless multiplier that accounts for the effect of wind in increasing the propagating flux ratio.
- ϕ_s (fē slope) is a dimensionless multiplier that accounts for the effect of slope in increasing the propagating flux ratio.
- ρ_b (rō) is a measure of the amount of fuel per cubic foot of fuel bed (lb/ft^3).
- ε (ep's -lon) is a measure of the proportion of a fuel particle that is heated to ignition temperature at the time flaming combustion starts.
- Q_{ig} is a measure of the amount of heat required to ignite 1 pound of fuel (Btu/lb).

Basically this equation shows that the rate at which fire spreads is a ratio of the heat received by the potential fuel ahead of the fire, to the heat required to ignite this fuel. Thus if fire can be thought of as a series of ignitions, it will progress through a fuel bed at the rate at which adjacent potential fuel can be heated to ignition temperature. Only a small portion of the heat produced in the flaming front of a wildland fire reaches nearby unignited fuel. The majority of the

heat is carried upward by convective activity or is radiated in other directions. The numerator of the above equation represents the amount of heat actually received by the potential fuel, while the denominator represents the amount of heat required to bring this fuel to ignition temperature.

Definition of Terms in the Spread Equation

This section presents a detailed explanation of how fuels, weather, and topographic inputs affect these terms. Your fuel modeling capabilities will be improved by understanding these relationships.

We will explain the concept of the spread equation by first defining the individual terms and briefly discussing what they represent. Then we will look at the terms in greater detail to examine how fuels, weather, and topography affect them.

REACTION INTENSITY (I_r)

Reaction Intensity (I_r) is a measure of the energy release rate, per unit area of the fire front. The units assigned to it are: Btu/ft^2/min. It is affected by:

1. Size of the individual fuel particles. Fuel particle size strongly influences fire spread and intensity. In almost all fire situations, the fire front advances through fine fuels such as grass, shrub foliage, or litter. Both the size of the particles and their compactness are important. The fire model uses a description of the fuel particle surface-area-to-volume ratio as the input describing particle size. The smaller the particle, the larger its surface-area-to-volume ratio. This can be visualized by cutting a fuel particle in half, lengthwise. The total volume of material remains the same, but additional surface area is contributed by each of the two cut surfaces. Thus the surface-area-to-volume ratio increases. This process is amplified as more cuts are made, producing ever smaller particles but more surface area.

For long, cylindrical objects such as conifer needles, twigs, and grasses, the area of the ends can be neglected, so the surface-area-to-volume ratio can be found by dividing the diameter into the number 4. For flat objects such as leaves that have very little area on their edges, the surface-area-to-volume ratio can be found by dividing the thickness into the number 2. The unit of feet is used for all measurements. For example, 1/4-inch diameter sticks have a surface-area-to-volume ratio of 192 ft^2/ft^3. The units are often simplified to 1/ft or ft^{-1}. Expressing diameter and thickness of small fuels in feet is awkward, but avoids the problem of wondering what units were used in various parts of the model. The mathematical symbol used to represent surface-area-to-volume ratio is the small Greek letter, sigma, σ.

When a fuel array is composed of different size particles, the fire model uses their individual surface areas, and the proportion of the total surface area contributed by each size class, to arrive at a characteristic size that represents the array. It is then assumed that the array would burn as if it were composed of only fuel particles of the characteristic size.

The timelag concept used in the National Fire-Danger Rating System (Fosberg and Deeming 1971) for describing fuel particle size of dead fuels is also used in NEWMDL and TSTMDL. Only the foliage and fine stems of living fuels are considered. These are described as either "herbaceous" for shallow-rooted grasses and herbaceous plants, or "woody" for deep-rooted shrubs. For woody plants, only the foliage and twigs less than 1/4-inch diameter are considered.

2. The compactness of the fuel bed, which is expressed as the packing ratio. At the two extremes, a fuel bed may contain no fuel--packing ratio is 0--or it may be a solid block of wood--packing ratio is 1. Thus, expressed as a percentage, the packing ratio is the percentage of the fuel bed that is composed of fuel, the remainder being air space between the individual fuel particles. A very

compact fuel bed burns slowly because airflow is impeded, and there are so many particles to be heated to ignition in a given length of the bed. A very open or porous fuel bed burns slowly because the individual fuel particles are spaced so far apart there is little heat transfer between them. That is, each particle in the fuel bed would burn as an individual. The maximum reaction intensity occurs at some intermediate packing ratio. The effect of fuel particle size and packing ratio upon the reaction intensity is incorporated in an important intermediate term called the reaction velocity. The reaction velocity is a ratio of how efficiently the fuel will be consumed to the burnout time of the characteristic fuel particle size. Therefore, fine fuel arrays arranged to burn most thoroughly in the shortest time have the largest reaction velocity. Fine fuel particles have higher reaction velocity in fuel arrays that are very loosely packed, whereas larger fuel particles need to be closer together to burn well.

Each size fuel particle has an optimum packing ratio. In the absence of wind the optimum packing ratio for any particle size is determined by a mathematical expression in the fire model. This relationship is illustrated in figure 8. In the presence of wind, the optimum packing ratio shifts to less tightly packed fuel arrays. The reaction velocity is depicted in figure 9 for a range of particle sizes and packing ratios. Note the sharp reduction in reaction velocity on either side of the optimum packing ratio.

Because the reaction intensity depends directly upon reaction velocity, it has the same dependence upon fuel particle size and packing ratio just described for reaction velocity.

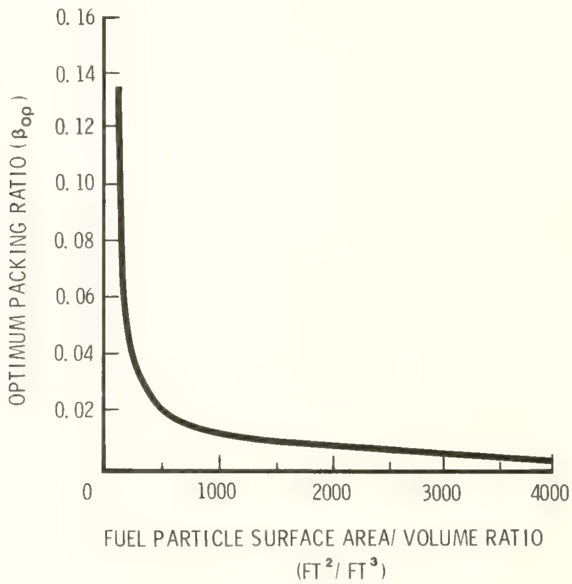

Figure 8.-- Optimum packing ratio. Fuel particle surface-area-to-volume ratio determines the optimum packing ratio for any fuel array.

3. Moisture content of the fuel. Higher moisture contents reduce reaction intensity because more of the heat released during combustion is required to evaporate the moisture. Less heat is available to raise the next fuel particle to ignition temperature.

4. Chemical composition. Although the quantity and type of inorganic material in the fuel affects the rate at which it burns, our primary concern is the heat content--the Btu's of heat released during combustion of 1 pound of fuel. The heat content is lowest for those fuels with few volatiles--oils and waxes--and higher for those

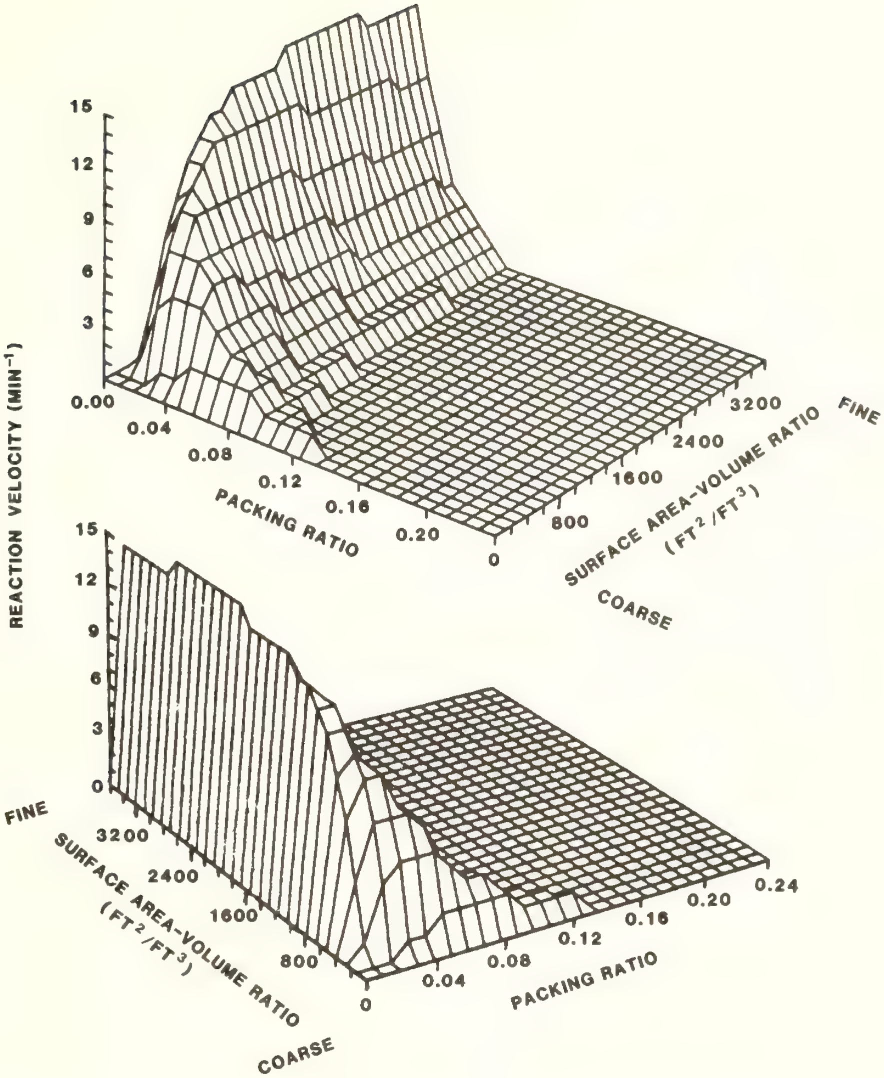

Figure 9.--Reaction velocity. The reaction velocity decreases sharply when the packing ratio is shifted from its optimum value for any given surface-area-to-volume ratio.

with more of them. Fuels having higher heat contents have more heat available per pound of fuel. The rate at which this heat will be released depends on the particle size, the packing ratio, the moisture content, and the mineral content of the fuels. At this time the effect of inorganic materials or minerals associated with salts in the fuel is not adjusted in NEWMDL or TSTMDL although it is variable in the fire model. The total salt content for all fuels is assumed constant at 5.55 percent for all fuel models and the effective salt content is assumed constant at 1.0 percent (Rothermel 1972).

To examine some of these points graphically, figure 10 illustrates that as the size of the individual fuel particles increases (surface-to-volume ratio gets smaller), they must be packed more tightly to maximize the reaction intensity. That is, the maximum reaction intensity for fine fuels occurs at a packing ratio of about 0.03 (3 percent of the fuel bed is wood), while it occurs at a packing ratio of about 0.08 for 1/4-inch sticks and 0.10 for 1/2-inch sticks. The packing ratio producing the maximum reaction intensity for a particular size fuel particle is called the optimum packing ratio. At the optimum packing ratio, the fuel/air mixture is optimized for efficient combustion. Figure 10 also illustrates that reaction intensity decreases

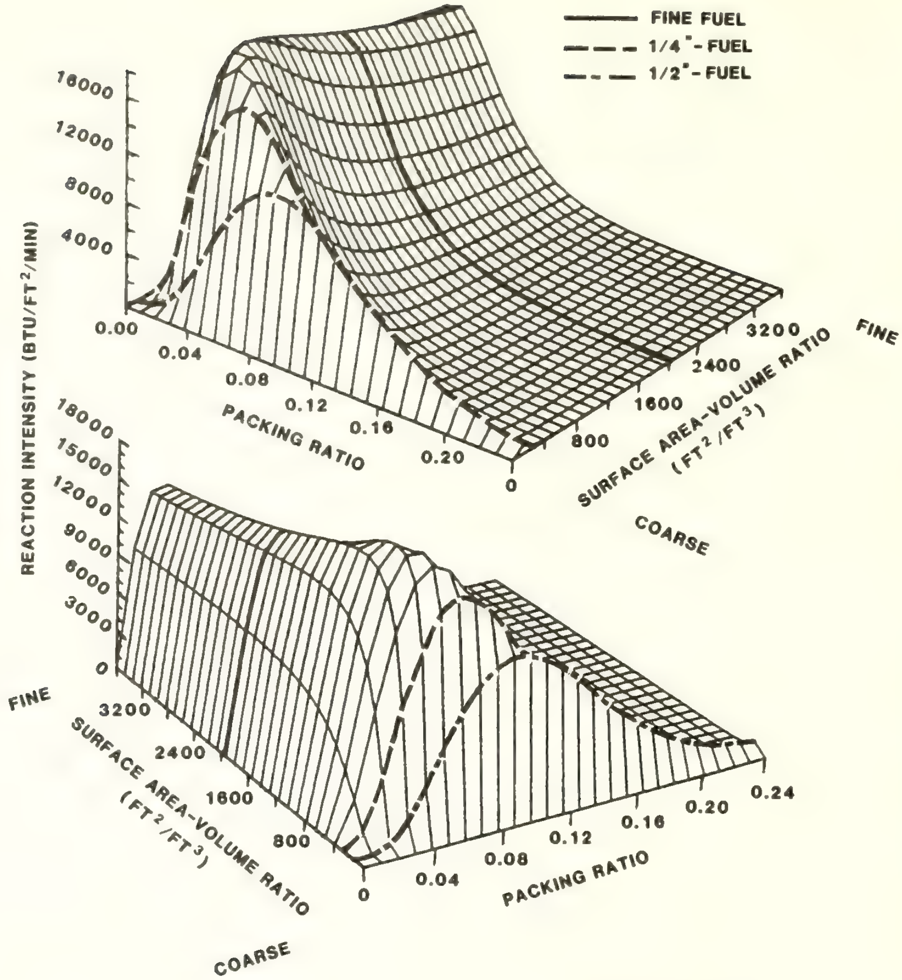

Figure 10.--Reaction intensity. The maximum reaction intensity occurs at higher packing ratios for larger fuel particles than for small ones. The reaction intensity decreases when the packing ratio is either less than or greater than optimum for any given fuel particle size.

when the packing ratio varies from its optimum value for any given fuel particle size.

From a fuel modeling standpoint, it is important to know that although the reaction intensity is maximized at the optimum packing ratio, this does not necessarily hold for rate of spread and flame length. Altering load and depth to adjust the packing ratio also affects the amount of heat required to ignite the fuel, as expressed by the denominator of the spread equation and the proportion of heat transferred to the fuel ahead of the fire as expressed by the propagating flux ratio ξ. Thus rate of spread and reaction intensity **do not** peak at the same packing ratio.

Tabular output from TSTMDL provides both the packing ratio for the model and a result labeled PR/OPR. The PR/OPR value is the ratio of actual packing ratio to optimum packing ratio. It is **less** than 1 if the packing ratio of the fuel model is less than optimum, 1 if they are equal, and **greater** than 1 if the fuel model packing ratio exceeds the optimum value. There is no rationale for attempting to adjust loads and depth until PR/OPR equals 1. In fact, it normally exceeds 1 for compact "horizontally oriented" fuels such as needle litter, but is usually less than 1 for vertical fuels such as

grass. This number will indicate how tightly your fuel model is packed should you want to make this comparison with one of the more familiar NFFL fuel models. Division of packing ratio by the PR/OPR value yields the optimum packing ratio.

The heat content is the only chemically oriented fuel model parameter users can change. Increasing the heat content always produces a "hotter" fuel model, while decreasing it reduces the calculated fire behavior.

Remember that reaction intensity (I_r) is the **total** heat release rate per unit area of fire front, and includes heat convected, conducted, and radiated in **all** directions, not just the direction of the adjacent potential fuel. The next term discussed serves to adjust this total energy release rate down to that portion which **is** effective in propagating the fire.

PROPAGATING FLUX RATIO (ξ)

The propagating flux is that portion of the total heat release rate from a fire, which is transferred and absorbed by the fuel ahead of the fire, raising its temperature to ignition. The propagating flux is calculated under the assumption that the fire is burning on a flat surface and in calm air (no wind, no slope). Effects of wind and slope are discussed later.

The parameter ξ in the rate of spread equation represents a ratio between this no-wind, no-slope propagating flux [$(I_p)_o$] and the reaction intensity (I_r). Mathematically it is defined as:

$$\xi = \frac{(I_p)_o}{I_r}$$

It expresses what proportion of the total reaction intensity (I_r) actually heats adjacent fuel particles to ignition. Propagating flux ratios can vary from zero--no heat reaches adjacent fuels--to 1--all of the heat reaches adjacent fuel. Realistically, and expressing the propagating flux ratio in percentage, typical values range from about 1 percent to 20 percent. Multiplying the first two terms in the numerator of the spread equation--reaction intensity times propagating flux ratio ($I_r\xi$)--produces the propagating flux, (I_p) which is an estimator of the rate of heat transfer that would drive the fire forward in a no-wind, no-slope situation.

The propagating flux ratio is affected by:

1. The average size of the fuel particles in the fuel bed, that is, the characteristic surface-to-volume ratio.
2. The packing ratio, or fuel bed compactness as explained previously.

Figure 11 shows the effect of both packing ratio and average fuel size on the propagating flux ratio. Note that at a constant packing ratio--0.04 is highlighted--the propagating flux ratio is greater for fine fuels than for coarse ones. As shown by figure 11, the propagating flux ratio tends to increase with increasing packing ratio, but the effect is much more pronounced in the finer fuels.

This implies that if fuel bed depth is kept constant and the dead fuel load (1-h, 10-h, and 100-h) is increased, thereby increasing the packing ratio, then a greater proportion of the heat produced by the fire will be effective in preheating the adjacent unburned fuel. This effect is more pronounced in the finer fuels. Remember, however, the reaction intensity is also strongly affected by the packing ratio. Reaction intensity will decrease if the fuel bed is **either** too tightly packed, or too loose. Similarly, the amount of fuel that must be heated to ignition is increased as fuel load is increased, thus illustrating that it is not easy to guess how fuel changes will affect fire behavior.

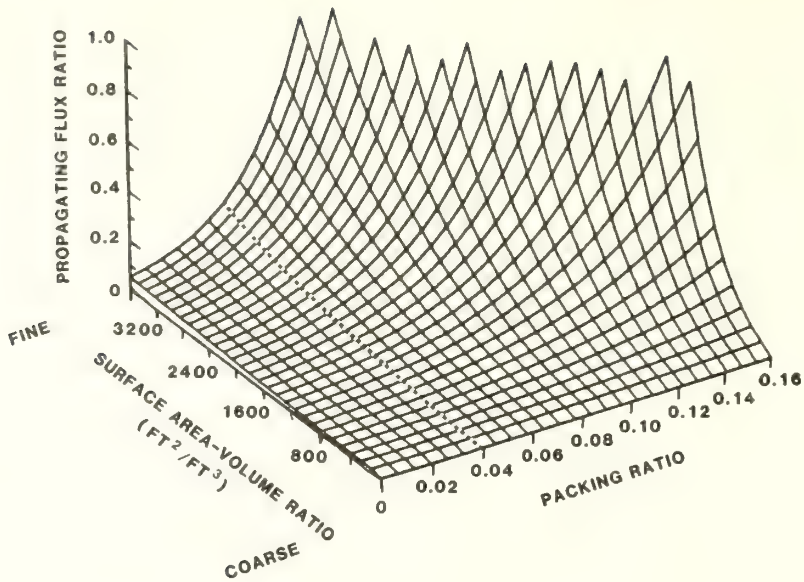

Figure 11.--Propagating flux ratio. The propagating flux ratio increases much faster for fine fuels than coarse ones, as the packing ratio increases. But at any packing ratio, the propagating flux ratio is higher for the finer fuels.

WIND COEFFICIENT (ϕ_w)

In the discussion of the no-wind propagating flux ratio (ξ) it was assumed there was no ambient wind and the terrain was flat (fig. 12). When this is not the case, wind and slope coefficients (ϕ_w) and (ϕ_s) are used by the fire model through the expression ($1+\phi_w+\phi_s$).

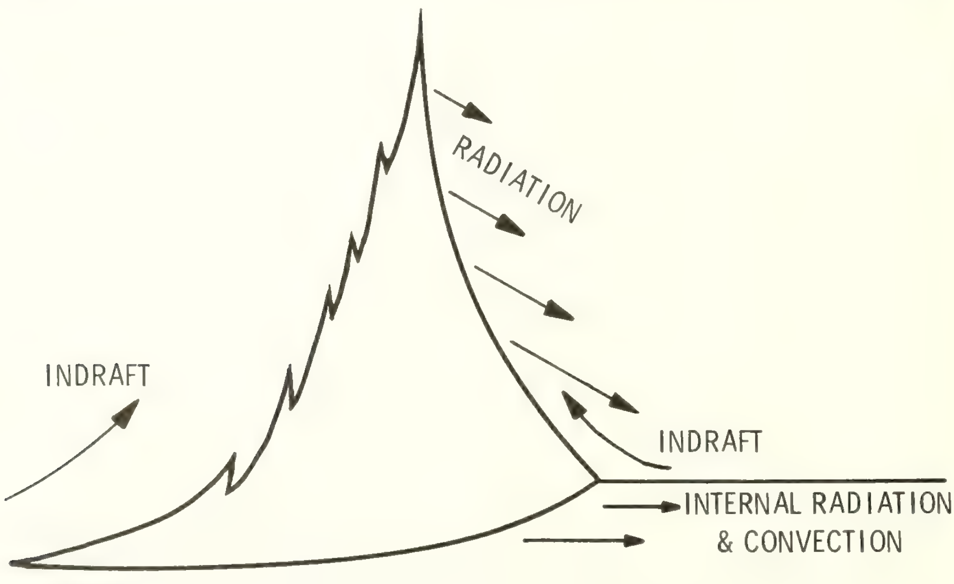

Figure 12.--Schematic of a no-wind fire.

Consider the no-slope case. The wind coefficient increases rapidly with windspeed in loosely packed fine fuels, thus greatly increasing spread rate. This occurs because wind tips the flame forward and causes direct flame contact with the fuel ahead of the fire as well as increased radiation from the flame to the fuel. This greatly increases transfer of radiant and convective heat to unburned fuel ahead of the fire (fig. 13).

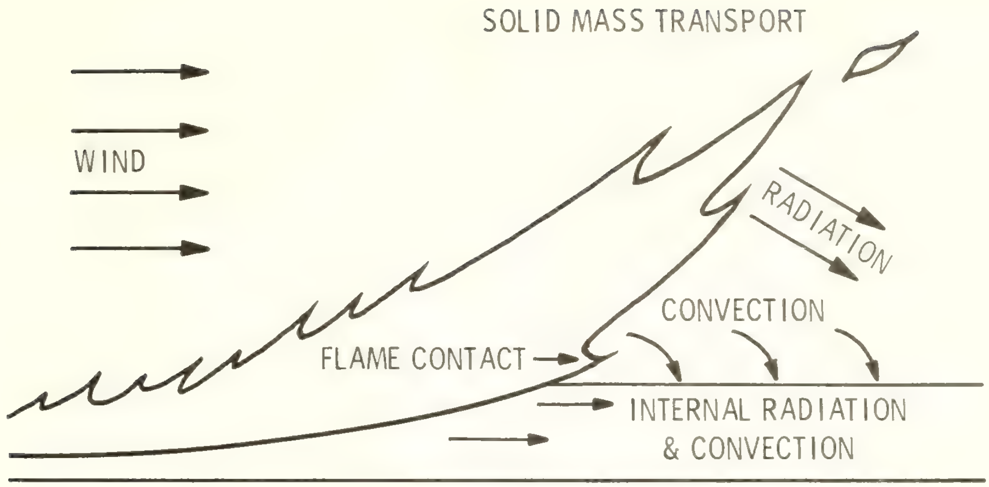

Figure 13.--Wind-driven fire. Increased radiant and convective heat transfer contributes to faster spread rates in wind-driven fires.

The wind coefficient is affected by:

1. The fuel bed's characteristic surface-area-to-volume (S/V) ratio. Figure 14 illustrates the effect of increasing the characteristic S/V ratio of a fuel bed whose packing ratio is half the optimum. Note that increasing the characteristic S/V ratio increases the wind coefficient, and that the effect is greater at higher windspeeds. A similar but less pronounced effect occurs for fuel beds with higher packing ratios.

2. The packing ratio of the fuel bed. For this discussion, a relative packing ratio is introduced. It is the ratio of the actual packing ratio divided by the optimum packing ratio. Its value is 1.0 when beds are packed optimally in the no-wind case. Figure 15 illustrates the effect of increasing packing ratio in a fuel bed whose characteristic S/V ratio is 1,500. Note that the wind coefficient decreases rapidly as the fuel bed is more tightly packed, and that the effect is more pronounced at low packing ratios. A similar but more pronounced effect occurs with finer fuels.

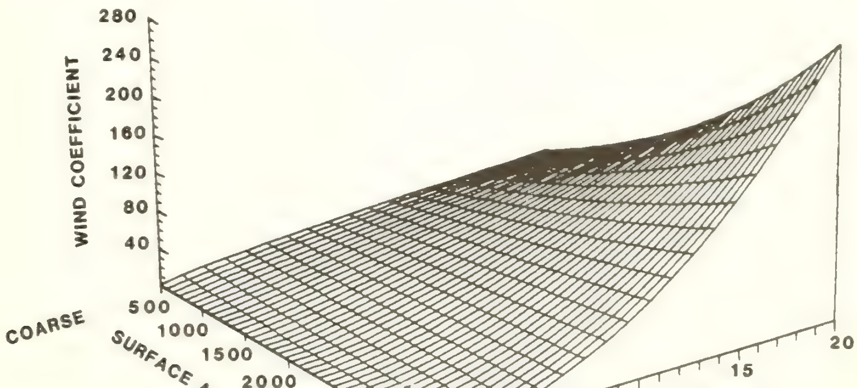

Figure 14.--Effect of fuel particle surface-area-to-volume ratio on wind coefficient. The effect of wind on fire increases more rapidly for fine fuel than for coarse fuel.

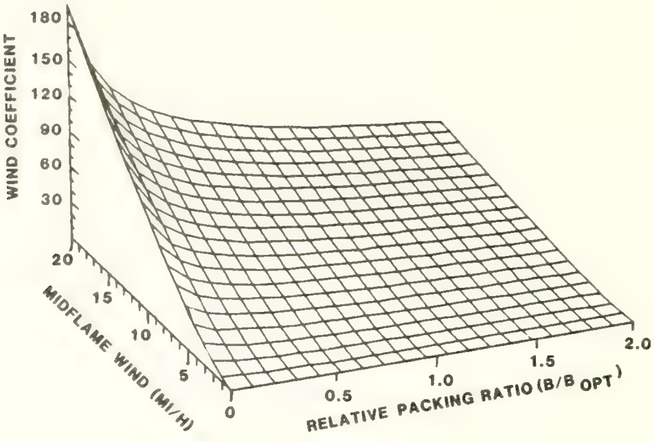

Figure 15.--Effect of packing ratio on the wind coefficient. Wind has a greater effect on fires in loosely packed fuels than tightly packed fuels, with this effect being more pronounced at low packing ratios.

3. The windspeed. Obviously an increase in windspeed will produce an increase in the wind coefficient. Even here there can be a limit which will be discussed soon.

The wind coefficient is increased by increasing the S/V ratio of the 1-h, live herbaceous, or live woody fuels. Reducing the packing ratio by either reducing the fuel load or increasing the fuel bed depth also increases the wind coefficient. Remember, however, that packing ratio also affects reaction intensity. So decreasing the packing ratio will increase the wind coefficient, but if the packing ratio falls below optimum, the reaction intensity will decrease even though the wind coefficient may be rather large.

Before leaving this discussion of wind's effect on fire behavior modeling, one note of caution is in order. That is, while wind generally increases fire spread rate and intensity, there is a limit to this effect. McArthur (1969) measured rate of spread on heading grassland fires in Australia and found that **excessive** wind actually **reduced** the spread rate (fig. 16). Although the fire model does not predict reduced spread rate at high windspeed, it does identify when maximum spread is reached. Further increases in windspeed will not give higher spread rates; the model will continue to predict the maximum for those fuel conditions. The effect is caused by the wind forces being stronger than the convective forces of the fire. This will occur when the effective windspeed (mi/h) equals 1/100 of the reaction intensity (Btu/ft^2/min). Effective windspeed is the no-slope midflame windspeed that produces the same spread rate as for a fire burning upslope and upwind. Effective windspeeds having a magnitude greater than $0.01I_r$ will not increase the calculated rate of spread. This wind limit may also be expressed as 9/10 of the reaction intensity when the windspeed is in **feet per minute.** This effect is most likely to be noticed with fuel models that represent sparse fuel types. For example, at 1 percent fuel moisture, NFFL model 1 (short grass) produces a maximum spread rate when the effective windspeed is 12 mi/h, while a 42 mi/h effective wind is required to reach the windspeed limit for NFFL model 3 (tall grass) at the same moisture content.

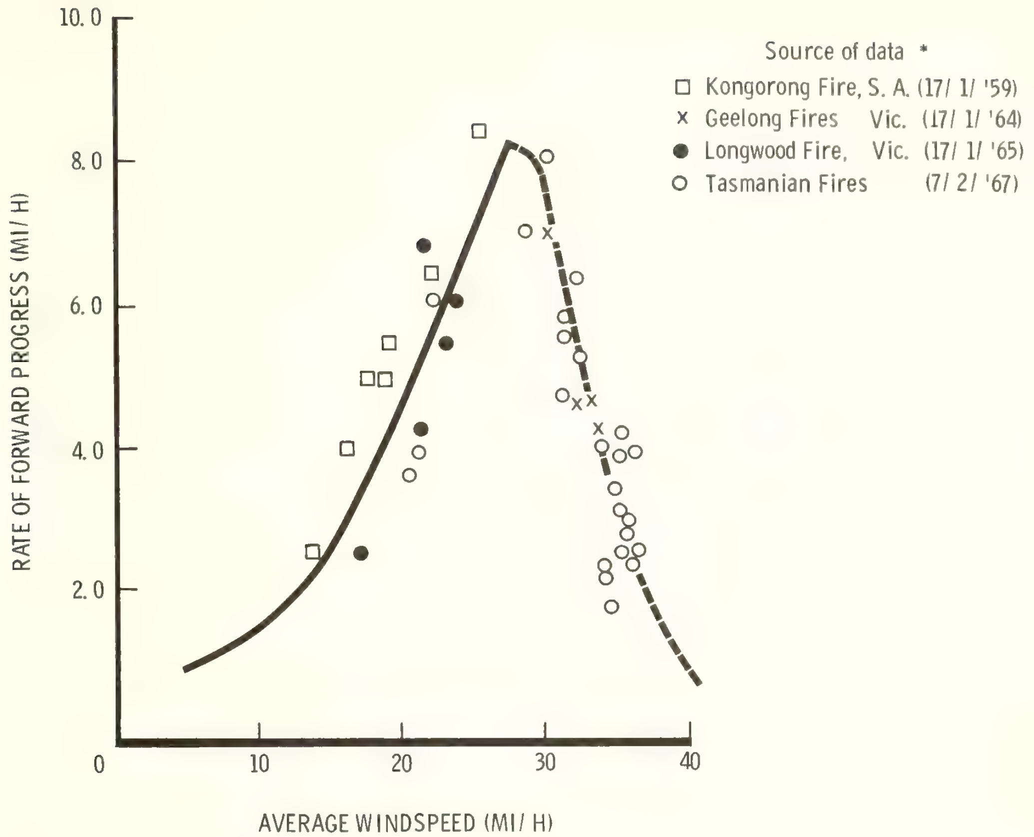

Figure 16.--Reproduction of McArthur's (1969) rate of spread data for grass. The windspeed was measured at a height of 33 feet above the ground in the open.

SLOPE COEFFICIENT (ϕ_s)

The effect of slope is introduced by the coefficient (ϕ_s) in the expression ($1 + \phi_w + \phi_s$). Wind is eliminated from this discussion by assuming the wind coefficient (ϕ_w) is zero. Then as the slope increases from 0 percent, where it does not affect spread rate, to some larger value, the rate of spread steadily increases. The mechanism producing this effect is the same as for wind--improved heat transfer because the flames are closer to unburned fuels on steeper slopes (fig. 17). The effect, however, is not as pronounced as it is with wind.

The slope coefficient is affected by:

1. Slope steepness. The slope coefficient increases as slope steepness increases. Negative slopes are not accepted by the model. A discussion of backing fires on slopes and cross-slope fire spread is given by Rothermel (1983).
2. The packing ratio of the fuel bed. As for the discussion on the wind coefficient, the effect of packing ratio is illustrated (fig. 18) from half to twice the optimum. The slope coefficient was determined for fine fuels, which are largely responsible for fire spread.

The packing ratio of a fuel model will slightly influence its sensitivity to slope steepness. This effect, however, is small relative to the magnitude of other effects produced by changes in packing ratio and so need not be of great concern to the fuel modeler. Changing fuel particle size does not affect the slope coefficient. Wind and slope are both recognized by the fire model, but there is no consideration of interactions between them.

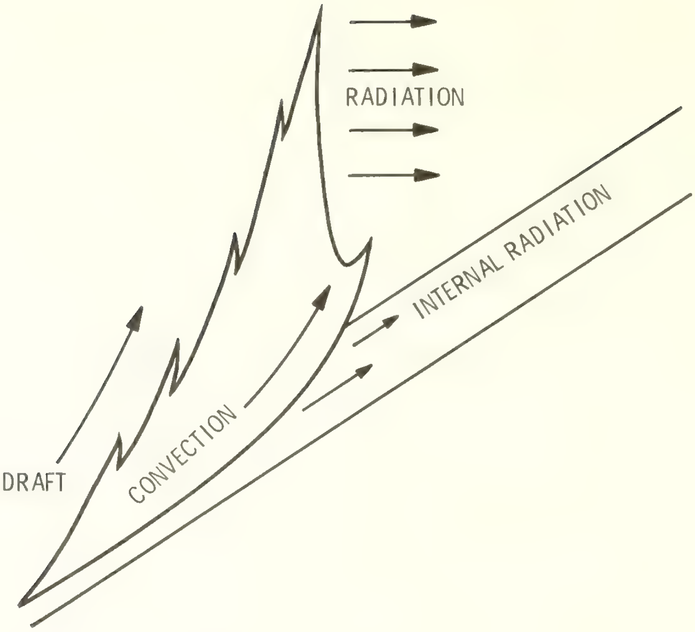

Figure 17.--Schematic of a fire on a slope.

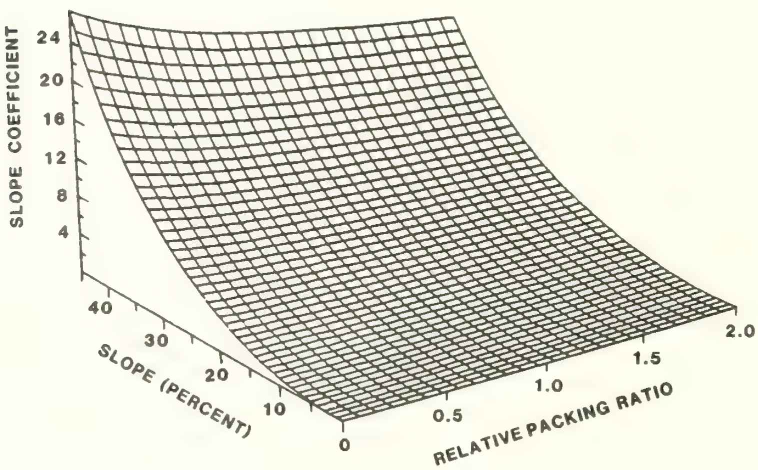

Figure 18.--Effect of packing ratio on the slope coefficient. Although fires spread faster upslope as slope steepness increases, the effect is much less than that of wind. The slope coefficient is affected little by packing ratio.

BULK DENSITY (ρ_b)

Bulk density is the first term to be discussed from the denominator of the rate of spread equation. Remember the denominator expresses the amount of heat required to bring the fuel to ignition temperature; that is, it represents a heat sink. Bulk density is the ovendry weight of fuel per cubic foot of fuel bed. The units are lb/ft^3. It is determined by dividing the fuel load (lb/ft^2) by the fuel bed depth (feet). Bulk density can be increased by increasing the fuel load or by decreasing the fuel bed depth. It serves as a basis for quantifying how much fuel is potentially available, per cubic foot of fuel bed, to act as a heat sink. Not all the fuel is necessarily heated to ignition; this is discussed in the section on the effective heating number.

It is important to realize the significance of having the bulk density in the denominator of the rate of spread equation. Increasing the bulk density tends to decrease the rate of spread because the total heat sink, as expressed by the denominator, is increased. This

effect, however, is altered by the influence of fuel load on the reaction intensity, and bulk density on the propagating flux ratio. Therefore, no absolute statement can be made with regard to the effect of altering fuel load or bulk density.

EFFECTIVE HEATING NUMBER (ε)

When large logs burn, the center of the log may be cool, relative to the surface that is on fire. That is, only the outer shell of the log has been heated to ignition temperature (320° C). The effective heating number (ε) provides the means to define what **proportion** of an individual fuel particle is heated to ignition temperature at the time flaming combustion starts. This proportion depends on the size of the fuel particle. Figure 19 shows that nearly the entire fuel particle for fine fuels is heated to ignition temperature at the time of ignition, while a relatively small proportion of larger fuels is heated to this degree. Multiplication of the bulk density by the effective heating number quantifies the amount of fuel, per cubic foot, that must be heated to ignition temperature as the fire progresses. That is, this product defines the **amount** of material in the heat sink.

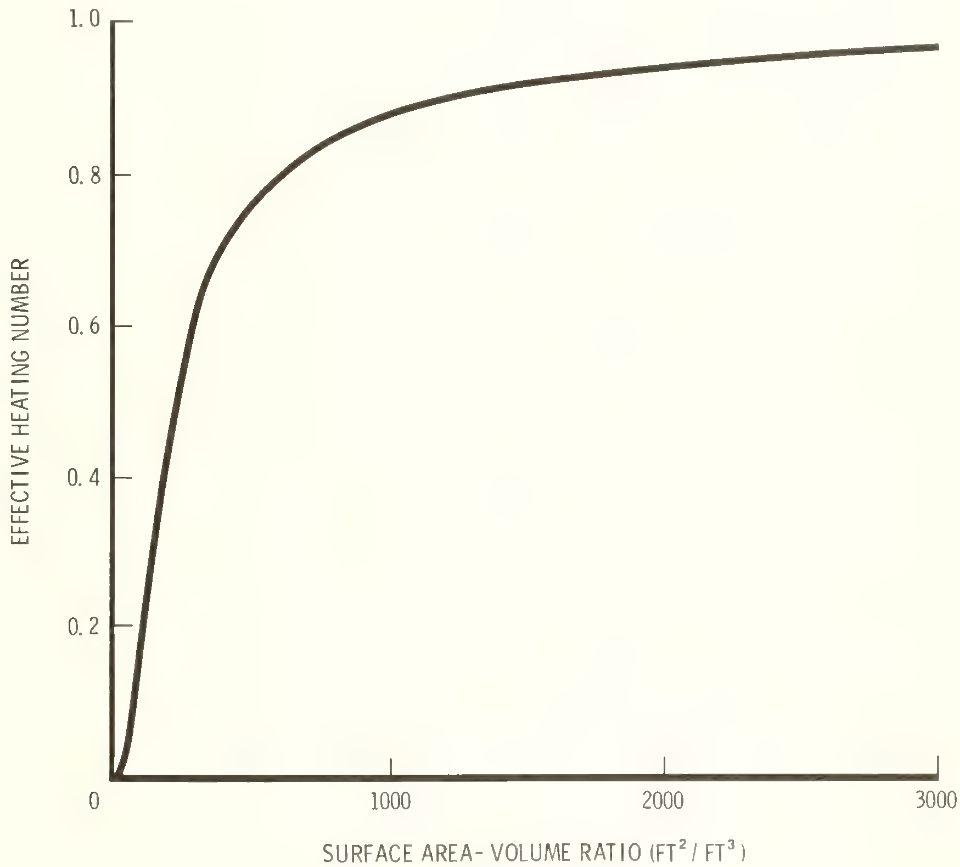

Figure 19.--Heating number. As fuel particle size decreases, a greater portion of the fuel particle is heated to ignition temperature at the time flaming combustion starts.

HEAT OF PREIGNITION (Q_{ig})

Heat of preignition (Q_{ig}) quantifies the amount of heat required to raise the temperature of 1 pound of moist wood from ambient temperature to the temperature at which it will ignite. In this process, first the water is evaporated from the wood, then the dry wood itself is heated. The amount of heat required to raise 1 pound of dry wood from air temperature to ignition temperature is a reasonably constant value that can be calculated in advance. The moisture content of wood, however, is not constant and it strongly affects the amount of

heat required to dry the fuel particle. Figure 20 shows that the heat of preignition increases steadily as the moisture content of the wood increases. Notice that even at zero percent moisture content, 250 Btu's are still required to heat each pound of absolutely dry wood to ignition.

Although the product of bulk density times effective heating number ($\rho_b \varepsilon$) quantifies how much **fuel weight**, per cubic foot of fuel bed, must be heated to ignition temperature, the heat of preignition quantifies how much **heat** is required to do this, per pound of moist fuel. Thus the units for Q_{ig} are Btu/lb. Then the product ($\rho_b \varepsilon Q_{ig}$) is the total amount of heat (Btu's) per cubic foot of fuel bed that must be supplied by the propagating flux.

The many interactions produced when fuel parameter values are changed preclude an exact description of how any particular change may affect predicted fire behavior. The technical version of TSTMDL was developed to provide an easy way to examine these changes graphically. You are strongly encouraged to use the technical graphics section of TSTMDL.

This completes a first look at each term in the rate of spread equation; however, additional fuel modeling insight can be gained from looking at some of these terms in greater detail, and from examining the method of weighting the influence of the various fuel size classes.

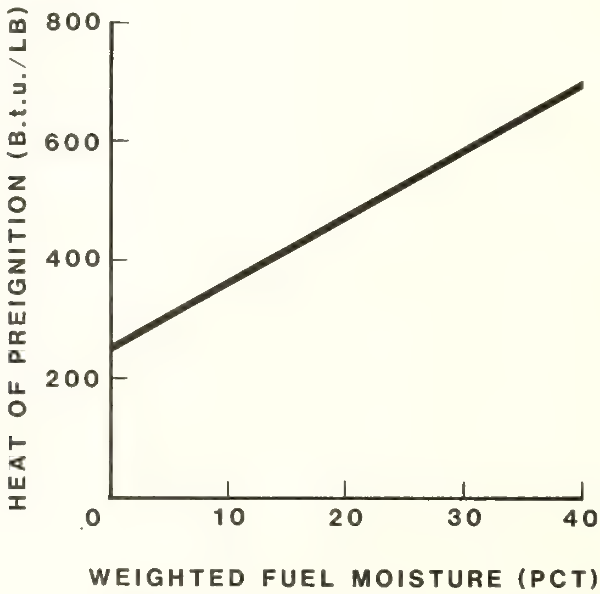

Figure 20.--Heat of preignition. The amount of heat required to ignite woody fuels increases as their moisture content increases.

Weighting of Fuel Size Classes

Even though a fuel model may contain several fuel size classes, each having a different surface-area-to-volume (S/V) ratio, σ, the mathematical fire model requires that just one S/V ratio value represent the entire fuel complex being modeled. The method of calculating this value weights the importance of each fuel class by its surface area, thus emphasizing the smaller fuels, which have the most effect on spread rate. A brief discussion of the weighting procedure may clarify some of the graphs produced by TSTMDL. Several tabulations will be used to help illustrate the weighting procedure, by placing an unusually large load in successive fuel classes. For these

tabulations, the S/V ratio of each fuel class will be assigned these constant values:

$$
\begin{aligned}
&\text{1-h S/V ratio } (\sigma_{1h}) &&= 2{,}000 \text{ ft}^2/\text{ft}^3\\
&\text{10-h S/V ratio } (\sigma_{10h}) &&= 109 \text{ ft}^2/\text{ft}^3\\
&\text{100-h S/V ratio } (\sigma_{100h}) &&= 30 \text{ ft}^2/\text{ft}^3\\
&\text{Live herbaceous S/V ratio } (\sigma_{hb}) &&= 1{,}800 \text{ ft}^2/\text{ft}^3\\
&\text{Live woody S/V ratio } (\sigma_{wd}) &&= 1{,}500 \text{ ft}^2/\text{ft}^3
\end{aligned}
$$

The fuel model loads for the six example cases will be:

Case number	Fuel model load (tons/acre) 1-h	10-h	100-h	Live herbaceous	Live woody
1	12	2	2	2	2
2	2	12	2	2	2
3	2	2	12	2	2
4	2	2	2	12	2
5	2	2	2	2	12
6	2	2	2	6	6

The first step in the weighting procedure is to determine the square feet of fuel surface area per square foot of fuel bed for each fuel size class. These values are determined for each size class by dividing the fuel particle density into the product of fuel particle S/V ratio times the ovendry load of that class. That is, the surface area of any given fuel class, per cubic foot of fuel bed, obtained by canceling equivalent units of measure is:

$$
\frac{\left(\dfrac{\text{ft}^2 \text{ of fuel surface area}}{\text{ft}^3 \text{ of fuel volume}}\right) \cdot \left(\dfrac{\text{lb of fuel}}{\text{ft}^2 \text{ of fuel bed}}\right)}{\left(\dfrac{\text{lb of fuel}}{\text{ft}^3 \text{ of fuel volume}}\right)} = \left(\frac{\text{ft}^2 \text{ of fuel surface area}}{\text{ft}^2 \text{ of fuel bed}}\right)
$$

These surface areas will be referred to as:

A_{1h} = ft^2 of 1-h fuel surface area per ft^2 of fuel bed

A_{10h} = ft^2 of 10-h fuel surface area per ft^2 of fuel bed

A_{100h} = ft^2 of 100-h fuel surface area per ft^2 of fuel bed

A_{hb} = ft^2 of live herbaceous fuel surface area per ft^2 of fuel bed

A_{wd} = ft^2 of live woody fuel surface area per ft^2 of fuel bed.

Then the surface areas for all the fuels in the dead category and the surface areas for all the fuels in the live category are summed separately:

$$A_{dead} = A_{1h} + A_{10h} + A_{100h}$$

$$A_{live} = A_{hb} + A_{wd}.$$

From these two sets of numbers, individual fuel class weighting factors are calculated by dividing the surface area in each fuel class by the total surface area in its category (live or dead):

$$f_{1h} = A_{1h}/A_{dead}$$

$$f_{10h} = A_{10h}/A_{dead}$$

$$f_{100h} = A_{100h}/A_{dead}$$

$$f_{hb} = A_{hb}/A_{live}$$

$$f_{wd} = A_{wd}/A_{live}.$$

The first three factors define the proportions of the total dead fuel surface area that are contributed by the 1-, 10-, and 100-h fuel classes, while the last two define the proportions of the total live fuel surface area that are contributed by the live herbaceous and woody fuel classes.

The magnitudes of these weighting factors for the six sample fuel models are shown in the listings below. Note that the heavily loaded fuel component has been underlined in each case.

Case number	Fuel class weighting factor				
	f_{1h}	f_{10h}	f_{100h}	f_{hb}	f_{wd}
1	<u>0.989</u>	0.009	0.002	0.545	0.455
2	.745	<u>.244</u>	.011	.545	.455
3	.874	.048	<u>.078</u>	.545	.455
4	.935	.051	.014	<u>.878</u>	.122
5	.935	.051	.014	.167	<u>.833</u>
6	.935	.051	.014	.545	.455

Because the S/V ratio for 1-h fuels is much greater than the S/V ratio for 10- and 100-h fuels, f_{1h} will generally be much larger than f_{10h} or f_{100h}. Thus the 1-h fuels dominate the dead fuel category. Live herbaceous and woody fuels often have similar S/V ratios, however, so f_{hb} and f_{wd} may be nearly equal. Note that the sum of the ratios in the live and dead categories of each case is 1.

The fuel class weighting factors are then used to determine a weighted S/V ratio for the dead and live categories by summing the products of the weighting factors for each class times the S/V ratio defined for that class.

$$\sigma_{dead} = f_{1h}*\sigma_{1h} + f_{10h}*\sigma_{10h} + f_{100h}*\sigma_{100h}$$

$$\sigma_{live} = f_{hb}*\sigma_{hb} + f_{wd}*\sigma_{wd}.$$

The weighted S/V ratios for the dead and live categories of the six sample fuel models are:

Case number	Weighted S/V ratios by fuel category	
	σ_{dead}	σ_{live}
1	1,978	1,663
2	1,517	1,663
3	1,755	1,663
4	1,876	1,763
5	1,876	1,530
6	1,876	1,663

To complete the discussion on calculation of a single fuel particle size or S/V ratio to represent the entire fuel bed, a final set of factors is calculated to define the proportion of the total fuel bed surface area that is contributed by each fuel category (dead and live).

$$f_{dead} = A_{dead}/(A_{dead} + A_{live})$$

$$f_{live} = A_{live}/(A_{dead} + A_{live})$$

For the sample fuel models, these are:

Case number	Fuel category weighting factors f_{dead}	f_{live}
1	0.786	0.214
2	.449	.551
3	.410	.590
4	.148	.852
5	.165	.835
6	.178	.822

Then the weighted S/V ratios for the dead and live categories are combined into a "characteristic" S/V ratio for the entire fuel complex. This is accomplished by adding the products of the weighting factor for each category times the weighted S/V ratio for that category:

$$\tilde{\sigma} = f_{dead} * \sigma_{dead} + f_{live} * \sigma_{live}.$$

The "characteristic" S/V ratios for the fuel model examples are:

Case number	Characteristic S/V ratio for the fuel model
1	1,911
2	1,597
3	1,700
4	1,780
5	1,604
6	1,701

The fire model assumes that fuel complexes composed entirely of particles having a "characteristic" S/V ratio of $\tilde{\sigma}$ would burn the same as the actual fuel complex being modeled, which usually contains several different fuel size classes.

From a fuel modeling standpoint, the "characteristic" S/V ratio, $\tilde{\sigma}$, is used numerous times in the fire model. In general, larger values suggest a faster combustion rate, therefore faster spread rate, greater flame lengths, increased response to wind and slope, etc. The "characteristic" S/V ratio is printed in tabular output of TSTMDL.

The most useful concept to remember from this discussion is that the relative magnitudes of the individual fuel class weighting factors greatly affect the response of a site specific fuel model to changes in fuel moisture. These weighting factors are primarily affected by the S/V ratios and loads of 1 h, live herbaceous and live woody loads, all of which can be varied in TSTMDL.

Response of Fuel Models to Fuel Moisture

Live and dead fuel moistures, live and dead moistures of extinction, and quantities of fine dead and live fuels all influence the response of a fuel model to fuel moisture changes.

As was described in the previous discussion on S/V weighting of fuel size classes, just one "characteristic" S/V ratio must represent the entire fuel complex. Similarly, a single "characteristic" dead fuel

moisture is determined to represent the average moisture content of the three dead fuel classes. The weighting procedure to determine a "characteristic" dead fuel moisture utilizes the same fuel class weighting factors (f_x) as described for the S/V weighting. Therefore the 1-h fuel moisture obviously dominates the "characteristic" dead fuel moisture because of the large S/V ratio associated with it.

For any fuel type, there exists a dead fuel moisture of extinction which is the lowest average dead fuel moisture at which a fire will not spread with a uniform front. By this definition, fuel will only burn if the actual moisture is less than the moisture of extinction. As the actual fuel moisture increases and approaches the moisture of extinction the fire will burn less vigorously. When dead fuels are dry enough to produce sufficient heat to desiccate and ignite the live fuels, these too contribute to the predicted fire intensity.

Fuel moistures affect both the numerator and denominator of the spread equation. The denominator is altered by changes in the heat of preignition (Q_{ig}); higher moistures increase Q_{ig}, lower values decrease it. Fuel moistures modify the numerator by altering the reaction intensity through a multiplier called the moisture-damping coefficient. As the "characteristic" dead fuel moisture approaches the dead moisture of extinction, the moisture-damping coefficient approaches zero, thus reducing the reaction intensity. Figure 21 illustrates the general shape of the moisture-damping coefficient curve. Graphs having this general shape are often produced by the

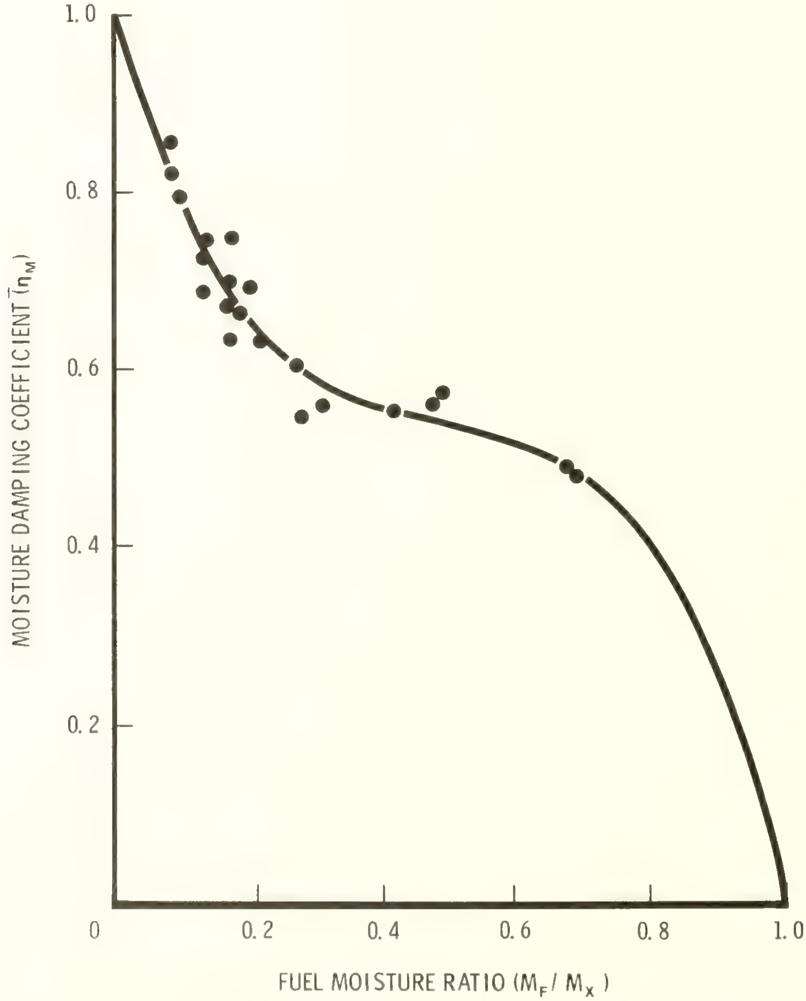

Figure 21.--Moisture damping curve. Fuels typically have an intermediate moisture range over which their sensitivity to changes in fuel moisture is minimized.

technical version of TSTMDL when rate of spread or flame length are plotted for a range of 1-h fuel moistures or loads. Increasing the dead moisture of extinction will lengthen the "flat" center portion of the curve indicating the fuel type being modeled will burn well under relatively high fuel moistures. The converse is true for lower dead fuel extinction moistures.

Dynamic fuel models react very differently from static models if they include a significant load of live herbaceous material. In dynamic models, material is transferred between the live herbaceous and the 1-h classes as the herbaceous moisture content ranges between 30 and 120 percent. This alters not only the load, but also the weighted moisture content of the live and dead fuel categories. The general result is that rapid changes in fire behavior predicted by static models for critical moisture ranges are less likely in dynamic models.

For fuel modeling, the most important concepts regarding fire behavior response to fuel moisture are:

1. Fuel classes having the highest S/V ratio (1-h, live herbaceous, and live woody) dominate the fuel moisture effects.
2. If the fuel type being modeled burns well at a relatively high moisture content, the model should have a high dead fuel moisture of extinction. If the fuels do not burn well at high moistures, the model should have a low moisture of extinction.
3. When combustion of the dead fuels produces enough heat to desiccate and ignite the live fuels, they too will add to the total fire intensity; otherwise they serve as a heat sink.
4. The dead moisture of extinction defines the "characteristic" moisture of dead fuels at which fire will not spread with a uniform front. Increasing the moisture of extinction will increase predicted fire behavior at all moisture levels--for example, fuels that burn well at high moisture levels should be given high values of moisture of extinction, 30 percent or more.
5. The fire behavior response of a fuel model to changes in fuel moistures is strongly affected by the relative loads in the fuel classes.
6. For dynamic models, herbaceous fuel moisture changes in the range of 30-120 percent produce fuel load transfers between the 1-h and the live herbaceous classes, thereby altering the moisture damping curve. The resulting fire behavior may be quite different than a similar static model.

General Techniques for Adjusting Fuel Models

This discussion section ends with general **guidelines** on how to adjust the fire behavior characteristics of a fuel model. It must be emphasized, however, that **guidelines only** can be provided. Interactions of the fuel model and environmental parameters with the fire model are so complex that "cookbook rules" cannot be substituted for a basic understanding of the fuel modeling process and examination of the models with TSTMDL. Fuel models should first be adjusted to perform well at low fuel moistures, then tested at higher fuel moistures to see if they respond properly there. The standard environmental conditions in the TSTMDL program provide a convenient means to set up low-, medium-, and high-moisture situations. If a fuel model must be adjusted to respond properly at high moistures, check the low-moisture response again to ensure that it is reasonable. All new fuel models should be well tested at all possible environmental conditions for which they may be used. This will help eliminate any undesired surprises in operational situations.

A common fuel-modeling problem is having the spread rate about right, but the flame length too low, or vice versa. The technical version of TSTMDL provides an opportunity to determine whether changing a particular fuel model parameter has a greater effect on the spread rate or the flame length. This can be accomplished by plotting the ratio of spread rate to flame length for a range of any fuel model or environmental parameter. Such a plot will show whether

spread rate will increase faster than flame length (rising curve) or slower (descending curve) as the value of the selected parameter changes (fig. 22). Modifying the fuel model parameters in the following order is a reasonable way to proceed.

1. Adjust loads.
    (a) 1-h timelag
    (b) live herbaceous
    (c) live woody
    (d) 10-h timelag
    (e) 100-h timelag
2. Adjust fuel bed depth.
3. Adjust surface-area-to-volume ratios.
    (a) 1-h timelag
    (b) live herbaceous
    (c) live woody
4. Adjust the extinction moisture for dead fuels.
5. Adjust the heat content.

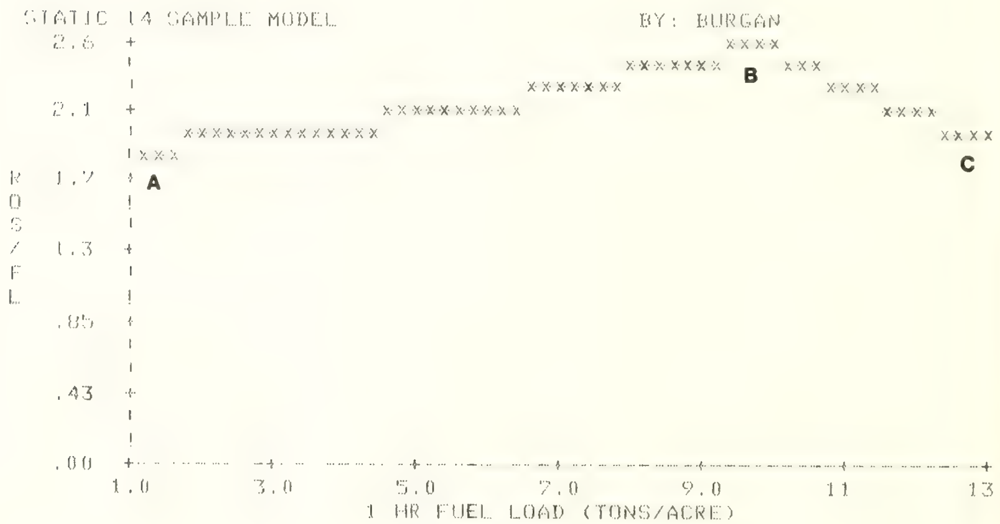

Figure 22.--Relative effect of 1-h timelag load on rate of spread vs flame length for this sample model. From A to B the rate of spread increases faster than flame length. From B to C flame length increases faster than rate of spread.

CHANGING FUEL LOAD

Fuel loads have both direct and indirect effects on every variable in the spread equation. Therefore because the load can be changed for any of the three dead and two live classes, a wide variety of responses can be produced. Usually an increase in fuel load will cause reaction intensity to increase more than rate of spread. In fact, the rate of spread may actually decrease because more fuel must be raised to ignition temperature. Addition of live herbaceous or woody fuels increases fuel model sensitivity to seasonal moisture changes in living vegetation. The general effect of live herbaceous fuel in dynamic models is to produce somewhat more intense fire behavior than static models when the live herbaceous moisture is between 30 and 120 percent. Transfer of "fine" fuel between the herbaceous and 1-h classes accounts for this.

The sensitivity of a fuel model to wind and slope can be increased by reducing the fuel load, thereby decreasing the packing ratio.

Because of the complex effects fuel load changes can produce, it is suggested that the technical version be used to plot rate of spread

and flame length over a wide range for any fuel load class you are investigating.

Increasing the 1-h load will generally increase the rate of spread and flame length until the fuel model becomes too tightly packed, then the rate of spread will decrease. Additional 10- or 100-h loads will generally decrease the rate of spread, but the flame length may either increase or decrease.

CHANGING FUEL BED DEPTH

Increasing fuel bed depth reduces the packing ratio, making a fuel model more sensitive to both wind and slope. Increasing depth also reduces the bulk density, which in turn reduces the heat sink (denominator of the spread equation), thus tending to increase the rate of spread. Increasing depth increases the reaction intensity if the packing ratio is greater than optimum (PR/OPR in TSTMDL tabular output is greater than 1), but decreases it if the packing ratio is less than optimum. Because both rate of spread and reaction intensity affect flame length, no absolute statements can be made about how depth changes will affect it.

CHANGING S/V RATIOS

In loosely packed fuels, increasing the S/V ratio of 1-h, live herbaceous, or live woody fuels will increase the rate of spread and flame length, and also increases the sensitivity of the fuel model to wind, but not to slope. Increasing the S/V ratio in tightly packed fuels, however, may decrease the spread rate and flame length.

CHANGING DEAD FUEL MOISTURE OF EXTINCTION

The greater the difference between the weighted dead moisture of the 1-, 10-, and 100-h fuels, and the dead fuel moisture of extinction, the more intense the predicted fire behavior. Dead moisture of extinction not only defines the weighted moisture content for dead fuels at which predicted fire behavior is zero, but also influences the fire intensity predicted at all fuel moisture levels. Increasing dead fuel extinction moisture produces a "hotter" fuel model at all moisture levels and increases the moisture at which the fire is predicted to stop spreading. Changes in moisture of extinction will produce more pronounced fire behavior response at high fuel moisture, however, than at low fuel moisture.

CHANGING HEAT CONTENT

Heat content affects all fire behavior outputs directly; higher heat content produces more intensive fire behavior, lower heat content reduces it. Because the effect of heat content is direct and predictable, it provides a means to "fine tune" a fuel model.

RECORDING AND USING SITE-SPECIFIC FUEL MODELS WITH THE TI-59 CALCULATOR

After developing, refining, and testing a fire behavior fuel model with the NEWMDL, TSTMDL, and BURN programs of the BEHAVE system, it can be recorded on a magnetic card for use in the field with a TI-59 calculator containing a fire behavior CROM. To obtain the values for a fuel model and the TI-59 registers in which to enter them, use program TSTMDL to first "load" the fuel model, either from your fuel model file, or by entering it directly. Entry of keyword TI59 in the "CONTROL" section of TSTMDL will list the values to enter in the TI-59 registers. A sample listing is shown in figure 23. Figure 24 provides a form on which you can record the values for your fuel model if you are not using a hard-copy terminal.

TI-59 Data for Static (Dynamic) Model XX Model Name

Model parameter	Parameter value	TI Reg. No.
-----Loads-----		
1-HR	0.0689	11
10-HR	0.0460	12
100-HR	0.0115	13
Live herbaceous	0.0459	15
Live woody	0.0688	16
---S/V ratio---		
1-HR	2000.	17
10-HR	109.	18
100-HR	30.	19
Live herb	1800.	21
Live woody	1700.	22
----Others----		
Heat content	8000.	23
ROS for IC	999999.	24
Ext moisture	30.	25
Depth	0.20	26
M WS constant	1.	27

To use static models in the TI-59, the live herbaceous and live woody loads have been combined in the live woody class, and the live herb load was set to zero. You must also enter the live herb and live woody S/V ratios as shown in the above listing, even though the herb load is zero.

Figure 23.--Sample TSTMDL listing needed to produce a fire behavior fuel model card for the TI-59 calculator.

TSTMDL TI-59 OUTPUT

Model number ____________

File name ____________

Wind reduction factor
for fully exposed fuels ________

Model parameter	Parameter value	TI Reg. No.
-----*Loads*----		
1-HR	________	11
10-HR	________	12
100-HR	________	13
Live herbaceous	________	15
Live woody	________	16
---*S/V ratio*---		
1-HR	________	17
10-HR	________	18
100-HR	________	19
Live herbaceous	________	21
Live woody	________	22
----*Others*----		
Heat content	________	23
Rate of spread for ignition component	________	24
Extinction moisture	________	25
Depth	________	26
M WS constant	________	27

Figure 24.--Site-specific fuel model recording form for TI-59.

Modifying the Keyboard Overlay

The fire behavior keyboard overlay was designed to define only one key for entry of LIVE fuel moisture. This key will continue to be used for entry of live fuel moisture for the 13 NFFL fuel models and for all **static** fuel models. For static models, a single average moisture is entered to represent both the live herbaceous and live woody fuels. To use **dynamic** fire behavior fuel models, however, the keyboard overlay must be modified to label a key for entering live

herbaceous fuel moisture. Place the label HERB above the INV key (fig. 25). Live herbaceous moisture can be entered by keying the moisture value into the display, then pressing SBR HERB. It can be recalled by pressing SBR 2nd HERB. Live woody fuel moisture can be entered using the key labeled LIVE.

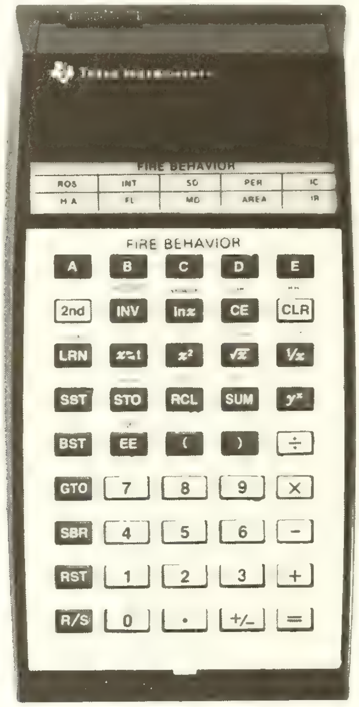

Figure 25.--Modify the fire behavior keyboard overlay by placing the label HERB above the INV key on the calculator.

Recording a Fuel Model

To record a site-specific fuel model on a TI-59 magnetic card, start with your calculator OFF to ensure all data registers are zeroed. Then perform the following steps:

1. Turn the calculator ON, then press 2nd PGM 2 SBR R/S. A -4. will appear in the display. Successively enter the values of the parameters listed for your fuel model into the display and store them in the indicated registers. For example, to store the 1-h timelag load illustrated in figure 23, enter .0689 in the display, and press STO 11. After all values for your model have been stored, put a -4 in the display, then press 2nd R/S and run a magnetic strip through the read/write slot in the calculator.

If your fuel model is static, that is it has no herbaceous load (register 15 is zero) the fuel model may be used as though it were one of the 13 NFFL models. Live fuel, when it occurs in static models, is stored in register 16 as live woody material. In this situation, step 2 does not apply.

2. If the fuel model is dynamic (register 15 is not zero), press RST LRN and enter the following program:

Step	Code	Keystrokes
000	76	2nd SBR
001	53	(
002	43	RCL
003	11	11
004	42	STO
005	94	94
006	43	RCL
007	15	15
008	42	STO
009	98	98
010	91	R/S
011	76	2nd SBR
012	54	)
013	43	RCL
014	94	94
015	42	STO
016	11	11
017	43	RCL
018	98	98
019	42	STO
020	15	15
021	91	R/S

Then press LRN 1 2nd R/S, turn the magnetic strip end for end, and run it through the read/write slot again. At this point you have the fuel model recorded on one side of the card and the above program on the other. Label the card.

Using a Fuel Model

1. To load any previously recorded fuel model with the TI-59--static or dynamic--press 2nd PGM 2 SBR R/S. A -4. will appear in the display.
2. Run the fuel model side of the card through the card reader.
3. If the model is static, the following steps do not apply; just use the model as though it were one of the 13 NFFL models.
4. If the model is dynamic, press 1 and then run the program side of the card through the card reader.
5. Press RST SBR (and ignore the number that appears in the display.
6. Press 2nd PGM 2 SBR R/S.
7. Enter or change environmental inputs--including herbaceous moisture.
8. Run the fire behavior program.
9. Press RST SBR)
10. To do another run, go back to step 6.

REFERENCES

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APPENDIX A: GRASS AND SHRUB FUEL TYPES

The photos in this appendix are meant to illustrate the general morphology for broadly different types of grasses and shrubs. That is, any set (page) of grass or shrub photos represents a **large** variety of grass or shrub species. One must select the photo that best fits the actual conditions at hand.

To help you visualize the general plant morphology each grass and shrub type is meant to represent, the specific species photographed are listed below:

Photo page	Species photographed	Morphology represented
Grass Type 1	Cheatgrass *Bromus tectorum*	Fine grasses
Grass Type 2	Rough fescue *Festuca scabrella*	Medium coarse grasses
Grass Type 3	Fountaingrass *Pennisetum ruppeli*	Coarse grasses
Grass Type 4	Sawgrass *Mariscus* spp.	Very coarse grasses
Shrub Type 1	Huckleberry *Vaccinium* spp.	Fine stems, thin leaves
Shrub Type 2	Ninebark *Physocarpus* spp.	Medium stems, thin leaves
Shrub Type 3	Ceanothus *Ceanothus* spp.	Medium stems, thick leaves
Shrub Type 4	Chamise *Adenostoma* spp.	Very dense, fine stems and leaves
Shrub Type 5	Manzanita *Arctostaphylos* spp.	Thick stems and leaves

GRASS TYPE 1

DENSITY 1

DENSITY 2

DENSITY 3

DENSITY 4

DENSITY 5

DENSITY 6

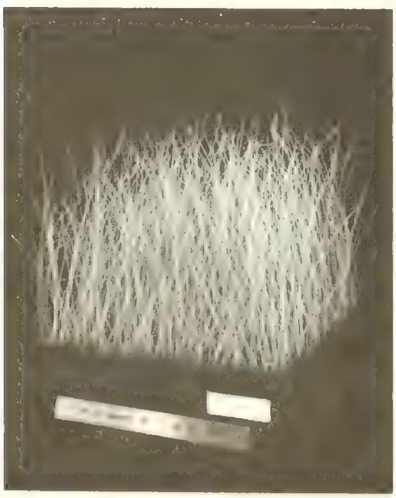
GRASS TYPE 2

DENSITY 1

DENSITY 2

DENSITY 3

DENSITY 4



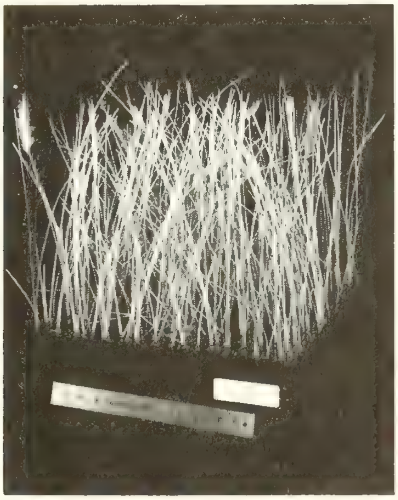
DENSITY 5

DENSITY 6

GRASS TYPE 3

DENSITY 1

DENSITY 2



DENSITY 3

DENSITY 4

DENSITY 5

DENSITY 6

GRASS TYPE 4

DENSITY 1

DENSITY 2

DENSITY 3

DENSITY 4

DENSITY 5

DENSITY 6

SHRUB TYPE 1

DENSITY 1

DENSITY 2

DENSITY 3

DENSITY 4

DENSITY 5

DENSITY 6

SHRUB TYPE 2

DENSITY 1

DENSITY 2

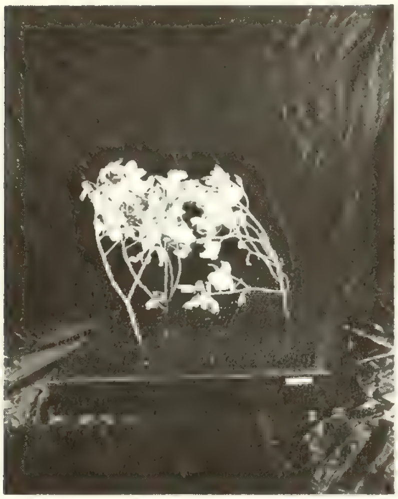
DENSITY 3

DENSITY 4

DENSITY 5

DENSITY 6

SHRUB TYPE 3



DENSITY 1

DENSITY 2

DENSITY 3

DENSITY 4

DENSITY 5

DENSITY 6

SHRUB TYPE 4

DENSITY 1

DENSITY 2

DENSITY 3

DENSITY 4

DENSITY 5

DENSITY 6

SHRUB TYPE 5

DENSITY 1

DENSITY 2

DENSITY 3

DENSITY 4

DENSITY 5

DENSITY 6

APPENDIX B: EXAMPLE NEWMDL SESSION

This NEWMDL session provides examples of various ways data can be entered when building a new fuel model. Not all possible data entry combinations are presented, but first-time or occasional users should find this listing helpful.

In this session, data have been entered for most of the fuel components in more than one way. This is to illustrate several procedures so you can refer to those of interest. It is not intended that you sign on to a computer and duplicate this session, although that may certainly be done.

The only fuel model file procedure used in this session is adding a model to the file. Extensive file manipulations are presented in the TSTMDL session (appendix C). Lines that begin with a prompt character (>) were typed by the user. All other lines were printed by the computer.

```
>NEWMDL

 WELCOME TO THE
   BEHAVE SYSTEM
     FUEL SUBSYSTEM
       NEWMDL PROGRAM (VERSION 2.0 -- AUGUST 1983)

 DEVELOPED BY THE
   FIRE BEHAVIOR RESEARCH WORK UNIT
   NORTHERN FOREST FIRE LABORATORY
   MISSOULA,MONTANA

 ENTER YOUR LAST NAME.
>BURGAN

 THE OBJECTIVE OF THIS PROGRAM IS TO HELP YOU DEVELOP
 A FIRE BEHAVIOR FUEL MODEL THAT REASONABLY CHARACTERIZES A
 FUEL COMPLEX NOT PROPERLY REPRESENTED BY ONE OF THE THIRTEEN
 NFFL FUEL MODELS.

 A TERSE MODE IS AVAILABLE FOR EXPERIENCED USERS
 THAT WANT LIMITED PROMPTING.  DO YOU WANT TERSE? (Y OR N).
>N

 FULL PROMPT MODE SET.

 PROGRAM CONTROL IS THROUGH THE USE OF KEYWORDS.
 DO YOU WANT A LIST OF KEYWORDS AND THEIR FUNCTIONS? (Y OR N)
>Y

 THE PRIMARY KEYWORDS AND THEIR FUNCTIONS ARE:
   KEYWORD       FUNCTION
    KEY       PRINTS THIS KEYWORD LIST
    TERSE     SET TERSE MODE FOR MINIMAL PROMPTING
    WORDY     SET WORDY MODE FOR FULL PROMPTING
    LITTER    DETERMINE LOAD OF LITTER FUELS
    GRASS     DETERMINE LOAD OF GRASS FUELS
    SHRUB     DETERMINE LOAD OF SHRUB FUELS
    SLASH     DETERMINE LOAD OF SLASH FUELS
    SURF      DETERMINE SURFACE TO VOLUME RATIOS
    HEAT      DETERMINE HEAT CONTENT
    COMP      DISPLAY VALUES OF FUEL COMPONENTS
    MODEL     DISPLAY FUEL MODEL
    RENUMBER  RENUMBER THE FUEL MODEL
    FILE      ACCESS FUEL MODEL FILE
    QUIT      QUIT SESSION
    RESTART   START PROGRAM AT BEGINNING AGAIN

 A FUEL MODEL MAY BE CONSTRUCTED WITH EITHER
    1.  1 SIZE OF FINE FUEL IN ONE OR MORE COMPONENTS
    2.  2 SIZES OF FINE FUEL IN ONE OR MORE COMPONENTS

 ENTER 1 OR 2
>1
```

Start of session

```
ENTER A NUMBER FOR YOUR PROPOSED FUEL MODEL.
RANGE = 14 TO 99
>60

ENTER FUEL MODEL NAME (32 CHARACTERS MAXIMUM).
--------------------------------
>FIRST SAMPLE MODEL

THE FUEL MODEL WILL BE BUILT UP FROM INDIVIDUAL
COMPONENTS -- LITTER, GRASS, SHRUBS, AND SLASH -- EACH
CONSIDERED SEPARATELY, BEFORE BEING COMBINED INTO A
COMPLETED FUEL MODEL.  ENTER THE KEYWORD FOR THE FIRST
COMPONENT YOU WISH TO CONSIDER.

CONTROL SECTION, KEYWORD?
>LITTER

LITTER SECTION

YOU CAN ENTER:
PREVIOUSLY INVENTORIED FUEL DATA
  1. LITTER LOAD BY SIZE CLASS (1, 10, 100 HR), AND DEPTH.
NEW FUEL DATA
  2. LITTER LOAD ONLY (DEPTH WILL BE ESTIMATED FOR YOU)
  3. LITTER DEPTH ONLY (LOAD WILL BE ESTIMATED FOR YOU)

*** CAUTION *** LITTER FUELS ARE OFTEN SHALLOW
SO THEIR DEPTH (IN FEET) IS USUALLY LESS THAN 1.
EX: 1 INCH = .083 FEET

ENTER 1, 2, OR 3
>1

ENTER LITTER LOAD (TONS/ACRE)
RANGE = 0 TO 30

1 HR?
>3

10 HR?
>4

100 HR?
>1

LITTER DEPTH IN FEET?
RANGE = 0 TO 5
>.2

WHAT PERCENT OF THE AREA IS COVERED BY LITTER?
>80

LITTER LOADS (T/A)
1 HR      2.40
10 HR     3.20
100 HR    0.80

LITTER DEPTH  0.16 FEET
LOADS AND DEPTH NOW REDUCED FOR AREA COVERAGE.
```

This procedure can be used to enter previously inventoried fuels data

Entering litter data by load and size class.

```
DO YOU WANT TO:
  1. ACCEPT THESE VALUES
  2. START THE LITTER SECTION ALL OVER?

ENTER 1 OR 2
>2

LITTER SECTION

YOU CAN ENTER:
PREVIOUSLY INVENTORIED FUEL DATA
  1. LITTER LOAD BY SIZE CLASS (1, 10, 100 HR), AND DEPTH.
NEW FUEL DATA
  2. LITTER LOAD ONLY (DEPTH WILL BE ESTIMATED FOR YOU)
  3. LITTER DEPTH ONLY (LOAD WILL BE ESTIMATED FOR YOU)

*** CAUTION *** LITTER FUELS ARE OFTEN SHALLOW
SO THEIR DEPTH (IN FEET) IS USUALLY LESS THAN 1.
EX: 1 INCH = .083 FEET

ENTER 1, 2, OR 3
>2

IS THE LITTER PRIMARILY FROM:
  1. CONIFERS
  2. HARDWOODS
  3. A COMBINATION OF BOTH, BUT AT LEAST 30% OF LESSER TYPE

ENTER 1, 2, OR 3
>3

WHAT IS THE NEEDLE LENGTH?
  1. MEDIUM TO LONG (EXAMPLE: LODGEPOLE OR PONDEROSA PINE)
  2. SHORT (EXAMPLE: DOUGLAS FIR)
ENTER 1 OR 2
>1

HOW COMPACT IS THE LITTER?
  1. LOOSE (FRESHLY FALLEN)
  2. NORMAL
  3. COMPACT (OLDER LITTER, COMPRESSED BY RAIN OR SNOW.)

ENTER 1, 2, OR 3
>2

ENTER TOTAL LITTER LOAD (TONS/ACRE).
RANGE = 0 TO 100
>7.5

THE CALCULATED AVERAGE LITTER DEPTH (FEET) IS 0.275
AT A LOAD OF  7.50 TONS/ACRE, FOR ACRES ACTUALLY COVERED WITH LITTER.

DO YOU WISH TO:
  1. ACCEPT THIS VALUE
  2. ENTER A NEW LITTER LOAD
  3. START THIS SECTION ALL OVER AGAIN

ENTER 1, 2, OR 3
>1
```

Entering litter data by load only

```
WHAT PERCENT, BY WEIGHT, OF THE LITTER LOAD IS 1 HR
TIMELAG FUEL?
>80

WHAT PERCENT, BY WEIGHT, OF THE LITTER LOAD IS 100 HR
TIMELAG FUEL?
>5

WHAT PERCENT OF THE AREA IS COVERED BY LITTER?
>90

LITTER LOADS (T/A)
1 HR      5.40
10 HR     1.01
100 HR    0.34

LITTER DEPTH  0.25 FEET
LOADS AND DEPTH NOW REDUCED FOR AREA COVERAGE.

DO YOU WANT TO:
   1. ACCEPT THESE VALUES
   2. START THE LITTER SECTION ALL OVER?

ENTER 1 OR 2
>1
```

Entering litter data by load only

```
OTHER FUEL COMPONENTS TO CONSIDER ARE:
GRASS
SHRUB
SLASH

IF THESE COMPONENTS ARE NOT PART OF THE FUEL COMPLEX
ENTER KEYWORD 'SURF'.

CONTROL SECTION, KEYWORD?
>GRASS

GRASS SECTION.

INCLUSION OF HERBACEOUS FUEL PROVIDES THE OPTION OF
DEVELOPING EITHER A DYNAMIC OR A STATIC FUEL MODEL

DYNAMIC MODELS ADJUST FOR SEASONAL DRYING THROUGH TRANSFER
OF LIVE HERBACEOUS LOAD BETWEEN LIVE HERBACEOUS AND 1 HOUR
TIMELAG CLASSES  AS A FUNCTION OF HERBACEOUS FUEL MOISTURE

STATIC MODELS HAVE CONSTANT LOADS IN ALL LIVE AND DEAD
FUEL CLASSES.

ENTER 1 OR 2
1 = DYNAMIC
2 = STATIC
>2
```

Entering grass data

```
YOU CAN ENTER:
PREVIOUSLY INVENTORIED FUEL DATA
   1. GRASS LOAD AND DEPTH
NEW FUEL DATA
   2. GRASS LOAD ONLY (DEPTH WILL BE ESTIMATED FOR YOU)
   3. GRASS DEPTH ONLY (LOAD WILL BE ESTIMATED FOR YOU)

ENTER 1, 2, OR 3
>1

TOTAL GRASS LOAD IN TONS/ACRE?
RANGE = 0 TO 30
>3

GRASS DEPTH IN FEET?
RANGE = 0 TO 10
>2

WHAT PERCENT OF THE TOTAL GRASS LOAD, BY VOLUME
IS GREEN?
PERCENT GREEN RANGE = 0 TO 100
>75

**CAUTION** MORE THAN 50 PERCENT GREEN MATERIAL IS
RARE EXCEPT WHERE NO LITTER OR STANDING DEAD STEMS REMAIN
FROM THE PREVIOUS GROWTH. ENTER PERCENT GREEN AGAIN TO
VERIFY YOUR ESTIMATE.
>50

WHAT PERCENT OF THE AREA IS COVERED BY GRASS?
RANGE = 0 TO 100
>50

GRASS LOADS (T/A)
1 HR        0.75
LIVE GRASS    0.75

GRASS DEPTH  1.00 FEET
LOADS AND DEPTH NOW REDUCED FOR AREA COVERAGE.

DO YOU WANT TO:
   1. ACCEPT THESE VALUES
   2. START THE GRASS SECTION ALL OVER?

ENTER 1 OR 2
>2
```

Entering grass data by load and depth

```
GRASS SECTION.

INCLUSION OF HERBACEOUS FUEL PROVIDES THE OPTION OF
DEVELOPING EITHER A DYNAMIC OR A STATIC FUEL MODEL

DYNAMIC MODELS ADJUST FOR SEASONAL DRYING THROUGH TRANSFER
OF LIVE HERBACEOUS LOAD BETWEEN LIVE HERBACEOUS AND 1 HOUR
TIMELAG CLASSES, AS A FUNCTION OF HERBACEOUS FUEL MOISTURE.

STATIC MODELS HAVE CONSTANT LOADS IN ALL LIVE AND DEAD
FUEL CLASSES.

ENTER 1 OR 2
1 = DYNAMIC
2 = STATIC
>1

YOU CAN ENTER:
PREVIOUSLY INVENTORIED FUEL DATA
  1. GRASS LOAD AND DEPTH
NEW FUEL DATA
  2. GRASS LOAD ONLY (DEPTH WILL BE ESTIMATED FOR YOU)
  3. GRASS DEPTH ONLY (LOAD WILL BE ESTIMATED FOR YOU)

ENTER 1, 2, OR 3
>3

WHICH GRASS TYPE IS MOST LIKE YOURS?
  1) FINE -- EX: CHEATGRASS
  2) MEDIUM -- EX: ROUGH FESCUE
  3) COARSE -- EX: FOUNTAINGRASS
  4) VERY COARSE -- EX: SAWGRASS
ENTER 1, 2, 3, OR 4
>3

WHICH DENSITY CLASS OF THIS TYPE IS MOST LIKE YOURS?
ENTER 1, 2, 3, 4, 5, OR 6
>5

GRASS DEPTH IN FEET?
RANGE = 0 TO 10
>2

THE CALCULATED TOTAL LOAD FOR ACRES ACTUALLY COVERED
WITH GRASS IS    3.27 TONS/ACRE.
AT A DEPTH OF    2.00 FEET.

DO YOU WANT TO:
  1. ACCEPT THIS VALUE
  2. ENTER A NEW DEPTH
  3. ENTER A NEW DENSITY
  4. ENTER A NEW GRASS TYPE
  5. START THE GRASS SECTION ALL OVER?
ENTER 1, 2, 3, 4 OR 5
>1
```

Entering grass data by depth only

```
WHAT IS THE MAXIMUM PERCENT OF THE TOTAL GRASS FUEL
LOAD, BY VOLUME, THAT CAN BE ALIVE (GREEN), REGARDLESS OF
HOW GREEN IT IS NOW?
PERCENT GREEN RANGE = 0 TO 100
>50

WHAT PERCENT OF THE AREA IS COVERED BY GRASS?
RANGE = 0 TO 100
>90

GRASS LOADS (T/A)
1 HR        1.47
LIVE GRASS    1.47

GRASS DEPTH  1.80 FEET
LOADS AND DEPTH NOW REDUCED FOR AREA COVERAGE.

DO YOU WANT TO:
   1. ACCEPT THESE VALUES
   2. START THE GRASS SECTION ALL OVER?

ENTER 1 OR 2
>1

OTHER FUEL COMPONENTS TO CONSIDER ARE:
SHRUB
SLASH

IF THESE COMPONENTS ARE NOT PART OF THE FUEL COMPLEX
ENTER KEYWORD 'SURF'.

CONTROL SECTION. KEYWORD?
>SHRUB

SHRUB SECTION.  YOU CAN ENTER:
PREVIOUSLY INVENTORIED FUEL DATA
   1. SHRUB LOAD BY CATEGORY (1, 10, 100 DEAD FUELS, LIVE
NEW FUEL DATA
        FOLIAGE AND TWIGS LESS THAN 1/4 INCH) AND DEPTH.
   2. SHRUB LOAD ONLY (DEPTH WILL BE ESTIMATED FOR YOU)
   3. SHRUB DEPTH ONLY (LOAD WILL BE ESTIMATED FOR YOU)

ENTER 1, 2, OR 3
>3
```

Entering grass data by depth only

Entering shrub data by depth only

```
WHICH SHRUB TYPE IS MOST LIKE YOURS?
ENTER 1, 2, 3, 4, OR 5
>2

WHICH DENSITY OF THIS TYPE IS MOST LIKE YOURS?
ENTER 1, 2, 3, 4, 5, OR 6
>4

SHRUB DEPTH IN FEET?
>4

THE CALCULATED AVERAGE SHRUB LOAD IS   6.00 TONS/ACRE.
AT A DEPTH OF    4.00 FEET, FOR ACRES ACTUALLY COVERED WITH SHRUBS.

DO YOU WANT TO:
   1. ACCEPT THIS VALUE
   2. ENTER A NEW DEPTH
   3. ENTER A NEW DENSITY
   4. ENTER A NEW SHRUB TYPE
   5. START THE SHRUB SECTION ALL OVER?
ENTER 1, 2, 3, 4 OR 5
>1

WHAT PERCENT, BY WEIGHT, OF THE SHRUB LOAD IS:
1 HR?
RANGE = 0 TO 100
>30

10 HR?
RANGE = 0 TO  70.0
>40

100 HR?
RANGE = 0 TO  30.0
>10

LIVING LEAVES AND TWIGS?
RANGE = 0 TO  20.0
>20

WHAT PERCENT OF THE AREA IS COVERED BY SHRUBS?
RANGE = 0 TO 100
>50

DO THE SHRUBS CONTAIN OILS OR WAXES THAT ENABLE THEM
TO BURN WHEN THEY ARE QUITE GREEN? (ENTER Y OR N).
>N

SHRUB LOADS (T/A)
1 HR       0.90
10 HR      1.20
100 HR     0.30
LEAVES & TWIGS    0.60

SHRUB DEPTH  2.00 FEET
LOADS AND DEPTH NOW REDUCED FOR AREA COVERAGE.
```

Entering shrub data by depth only

```
DO YOU WANT TO:
   1. ACCEPT THESE VALUES
   2. START THE SHRUB SECTION ALL OVER?

ENTER 1 OR 2
>1

OTHER FUEL COMPONENTS TO CONSIDER ARE:
SLASH

IF THESE COMPONENTS ARE NOT PART OF THE FUEL COMPLEX
ENTER KEYWORD 'SURF'

CONTROL SECTION. KEYWORD?
>SLASH
```

Direct entry of previously inventoried slash data

```
SLASH SECTION.  YOU CAN:
   1. INPUT YOUR INVENTORIED DATA ON LOAD BY SIZE CLASS, AND DEPTH

   2. USE RELATIONSHIPS DEVELOPED FROM RESEARCH DATA FOR
      INTERMOUNTAIN CONIFERS. ** CAUTION ** THESE RELATIONSHIPS
      ARE PROBABLY NOT VALID WEST OF THE CASCADES OR EAST OF
      THE ROCKY MOUNTAINS.

ENTER 1 OR 2
>1

ENTER LOAD (TONS/ACRE) FOR:
1 HR? -- THIS MEANS LOAD OF 0-1/4 INCH TWIGS PLUS AIR
DRY NEEDLES STILL ATTACHED TO THE BRANCHES.
RANGE = 0 TO 30
>3

10 HR?
>5

100 HR?
>10

SLASH DEPTH IN FEET?
RANGE = 0 TO 10
>2
```

If your inventory procedure was to sample only where the slash existed and not the bare areas, then enter the percent of the area covered by slash. That was assumed to be the case for this example.

```
WHAT PERCENT OF THE AREA IS COVERED BY SLASH?
RANGE = 0 TO 100
>40

SLASH LOADS (T/A)
1 HR       1.20
10 HR      2.00
100 HR     4.00

SLASH DEPTH  0.80 FEET
```

If your inventory procedure was to sample the entire area, both where the slash existed and where it did not, enter 100 as the percent of area covered by slash. Then your inventoried slash load will not be reduced.

```
DO YOU WANT TO:
   1. ACCEPT THESE VALUES
   2. START THE SLASH SECTION ALL OVER?

ENTER 1 OR 2
>2

SLASH SECTION.  YOU CAN:
   1. INPUT YOUR INVENTORIED DATA ON LOAD BY SIZE CLASS, AND DEPTH

   2. USE RELATIONSHIPS DEVELOPED FROM RESEARCH DATA FOR
      INTERMOUNTAIN CONIFERS. ** CAUTION ** THESE RELATIONSHIPS
      ARE PROBABLY NOT VALID WEST OF THE CASCADES OR EAST OF
      THE ROCKY MOUNTAINS.

ENTER 1 OR 2
>2

WHICH BEST DESCRIBES THE ORIGIN OF THE SLASH?
   1. COMMERCIAL TIMBER CUT, HIGHLEAD SKIDDING
   2. COMMERCIAL TIMBER CUT, GROUNDLEAD SKIDDING
   3. PRECOMMERCIAL THINNING.

ENTER 1, 2, OR 3
>3

ENTER SLASH AGE IN YEARS.
RANGE = 0 TO 5
>2

TO PROCEED FURTHER YOU MUST HAVE FUEL INFORMATION IN
ONE OF FOUR FORMATS, OR ELSE END CONSIDERATION OF SLASH.
   1. TOTAL SLASH LOAD IN TONS PER ACRE
   2. LOAD OF 10 HR FUELS ONLY, IN TONS PER ACRE
   3. 10 HR LOAD IN TONS PER ACRE, BY SPECIES
   4. NUMBER OF 10 HR INTERCEPTS PER FOOT, BY SPECIES
   5. END SLASH INPUTS, PROPER DATA UNAVAILABLE

ENTER 1, 2, 3, 4, OR 5
>1

ENTER THE TOTAL SLASH LOAD IN TONS PER ACRE.
RANGE = .01 TO 100
>18

FOR EACH SPECIES YOU FEEL CONTRIBUTES SIGNIFICANTLY TO
THE SLASH LOAD, YOU WILL BE ASKED ITS PRE-HARVEST AVERAGE
CROWN CLASS (DOMINANT OR INTERMEDIATE), AVERAGE DBH, AND
PERCENT OF THE SLASH LOAD CONTRIBUTED BY THIS SPECIES.
```

Entry of total slash load

```
FUEL MODELING ASSISTANCE IS AVAILABLE FOR THESE SPECIES:

 SPECIES CODE        SPECIES NAME
 ------------        ------------
       GF           GRAND FIR
       WL           WESTERN LARCH
       ES           ENGELMANN SPRUCE
       AF           SUBALPINE FIR
       LP           LODGEPOLE PINE
       WP           WESTERN WHITE PINE
       WB           WHITEBARK PINE
       WC           WESTERN RED CEDAR
       PP           PONDEROSA PINE
       DF           DOUGLAS FIR
       WH           WESTERN HEMLOCK

 ENTER SPECIES CODE.
>WL

 ENTER CROWN CLASS AS:
   1. DOMINANT
   2. INTERMEDIATE

 ENTER 1 OR 2
>1

 ENTER AVERAGE DBH (INCHES) FOR THIS SPECIES.

 RANGE = 1 TO 100
>8

 ENTER PERCENT OF SLASH CONTRIBUTED BY THIS SPECIES
 RANGE = 0 TO 100
>60

 IS THIS THE LAST SPECIES YOU ARE GOING TO ENTER? (Y OR N)
>N

 ENTER SPECIES CODE.
>DF

 ENTER CROWN CLASS AS:
   1. DOMINANT
   2. INTERMEDIATE

 ENTER 1 OR 2
>2

 ENTER AVERAGE DBH (INCHES) FOR THIS SPECIES.

 RANGE = 1 TO 100
>6
```

Entry of total slash load

```
ENTER PERCENT OF SLASH CONTRIBUTED BY THIS SPECIES
RANGE = 0 TO 100
>40

IS THIS THE LAST SPECIES YOU ARE GOING TO ENTER? (Y OR N)
>Y

YOU CAN EITHER:
1. USE COMPUTER ADJUSTMENTS FOR FOLIAGE AND TWIG RETENTION
2. USE YOUR ESTIMATES OF FOLIAGE AND TWIG RETENTION
ENTER 1 OR 2
>1

WHAT PERCENT OF THE AREA IS COVERED BY SLASH?
RANGE = 0 TO 100
>30

SLASH LOADS (T/A)
1 HR       1.74
10 HR      1.76
100 HR     0.51

SLASH DEPTH  0.49 FEET

DO YOU WANT TO:
  1. ACCEPT THESE VALUES
  2. START THE SLASH SECTION ALL OVER?

ENTER 1 OR 2
>2
```

Entry of total slash load

```
SLASH SECTION.  YOU CAN:
  1. INPUT YOUR INVENTORIED DATA ON LOAD BY SIZE CLASS, AND DEPTH

  2. USE RELATIONSHIPS DEVELOPED FROM RESEARCH DATA FOR
     INTERMOUNTAIN CONIFERS. ** CAUTION ** THESE RELATIONSHIPS
     ARE PROBABLY NOT VALID WEST OF THE CASCADES OR EAST OF
     THE ROCKY MOUNTAINS.

ENTER 1 OR 2
>2

WHICH BEST DESCRIBES THE ORIGIN OF THE SLASH?
  1. COMMERCIAL TIMBER CUT, HIGHLEAD SKIDDING
  2. COMMERCIAL TIMBER CUT, GROUNDLEAD SKIDDING
  3. PRECOMMERCIAL THINNING.

ENTER 1, 2, OR 3
>3

ENTER SLASH AGE IN YEARS.
RANGE = 0 TO 5
>2
```

Entry of total 10 hour load

```
TO PROCEED FURTHER YOU MUST HAVE FUEL INFORMATION IN
ONE OF FOUR FORMATS, OR ELSE END CONSIDERATION OF SLASH.
   1. TOTAL SLASH LOAD IN TONS PER ACRE
   2. LOAD OF 10 HR FUELS ONLY, IN TONS PER ACRE
   3. 10 HR LOAD IN TONS PER ACRE, BY SPECIES
   4. NUMBER OF 10 HR INTERCEPTS PER FOOT, BY SPECIES
   5. END SLASH INPUTS, PROPER DATA UNAVAILABLE

ENTER 1, 2, 3, 4, OR 5
>2

ENTER TOTAL 10 HR LOAD IN TONS PER ACRE.
RANGE = .01 TO 30
>4.5

FOR EACH SPECIES YOU FEEL CONTRIBUTES SIGNIFICANTLY TO
THE SLASH LOAD, YOU WILL BE ASKED ITS PRE-HARVEST AVERAGE
CROWN CLASS (DOMINANT OR INTERMEDIATE), AVERAGE DBH, AND
PERCENT OF THE SLASH LOAD CONTRIBUTED BY THIS SPECIES.

FUEL MODELING ASSISTANCE IS AVAILABLE FOR THESE SPECIES:

SPECIES CODE        SPECIES NAME
------------      ----------------
     GF           GRAND FIR
     WL           WESTERN LARCH
     ES           ENGELMANN SPRUCE
     AF           SUBALPINE FIR
     LP           LODGEPOLE PINE
     WP           WESTERN WHITE PINE
     WB           WHITEBARK PINE
     WC           WESTERN RED CEDAR
     PP           PONDEROSA PINE
     DF           DOUGLAS FIR
     WH           WESTERN HEMLOCK

ENTER SPECIES CODE.
>LP

ENTER CROWN CLASS AS:
   1. DOMINANT
   2. INTERMEDIATE

ENTER 1 OR 2
>1

ENTER AVERAGE DBH (INCHES) FOR THIS SPECIES.

RANGE = 1 TO 100
>6

ENTER PERCENT OF SLASH CONTRIBUTED BY THIS SPECIES
RANGE = 0 TO 100
>100
```

Entry of total 10 hour load

```
 IS THIS THE LAST SPECIES YOU ARE GOING TO ENTER? (Y OR N)
>Y

 YOU CAN EITHER:
 1. USE COMPUTER ADJUSTMENTS FOR FOLIAGE AND TWIG RETENTION
 2. USE YOUR ESTIMATES OF FOLIAGE AND TWIG RETENTION
 ENTER 1 OR 2
>2

 ENTER PERCENT FOLIAGE STILL ON LODGEPOLE PINE
 RANGE = 0 TO 100
>50

 ENTER AVERAGE PERCENT TWIG (0 TO 1/4 INCH) RETENTION FOR ALL SPECIES
 RANGE = 0 TO 100
>80

 WHAT PERCENT OF THE AREA IS COVERED BY SLASH?
 RANGE = 0 TO 100
>50

 SLASH LOADS (T/A)
 1 HR      3.27
 10 HR     2.25
 100 HR    0.29

 SLASH DEPTH  0.79 FEET

 DO YOU WANT TO:
   1. ACCEPT THESE VALUES
   2. START THE SLASH SECTION ALL OVER?

 ENTER 1 OR 2
>2
```

Entry of total 10 hour load

```
 SLASH SECTION.  YOU CAN:
   1. INPUT YOUR INVENTORIED DATA ON LOAD BY SIZE CLASS, AND DEPTH

   2. USE RELATIONSHIPS DEVELOPED FROM RESEARCH DATA FOR
      INTERMOUNTAIN CONIFERS. ** CAUTION ** THESE RELATIONSHIPS
      ARE PROBABLY NOT VALID WEST OF THE CASCADES OR EAST OF
      THE ROCKY MOUNTAINS.

 ENTER 1 OR 2
>2

 WHICH BEST DESCRIBES THE ORIGIN OF THE SLASH?
   1. COMMERCIAL TIMBER CUT, HIGHLEAD SKIDDING
   2. COMMERCIAL TIMBER CUT, GROUNDLEAD SKIDDING
   3. PRECOMMERCIAL THINNING.

 ENTER 1, 2, OR 3
>2
```

Entry of 10 hour load by species

```
 ENTER SLASH AGE IN YEARS.
 RANGE = 0 TO 5
>3

 TO PROCEED FURTHER YOU MUST HAVE FUEL INFORMATION IN
 ONE OF FOUR FORMATS, OR ELSE END CONSIDERATION OF SLASH.
   1. TOTAL SLASH LOAD IN TONS PER ACRE
   2. LOAD OF 10 HR FUELS ONLY, IN TONS PER ACRE
   3. 10 HR LOAD IN TONS PER ACRE, BY SPECIES
   4. NUMBER OF 10 HR INTERCEPTS PER FOOT, BY SPECIES
   5. END SLASH INPUTS, PROPER DATA UNAVAILABLE

 ENTER 1, 2, 3, 4, OR 5
>3

 FOR EACH SPECIES YOU FEEL CONTRIBUTES SIGNIFICANTLY TO
 THE SLASH LOAD, YOU WILL BE ASKED ITS PRE-HARVEST AVERAGE
 CROWN CLASS (DOMINANT OR INTERMEDIATE), AVERAGE DBH, AND
 10 HR LOAD IN TONS PER ACRE.

 FUEL MODELING ASSISTANCE IS AVAILABLE FOR THESE SPECIES:

 SPECIES CODE      SPECIES NAME
 ------------     --------------
      GF          GRAND FIR
      WL          WESTERN LARCH
      ES          ENGELMANN SPRUCE
      AF          SUBALPINE FIR
      LP          LODGEPOLE PINE
      WP          WESTERN WHITE PINE
      WB          WHITEBARK PINE
      WC          WESTERN RED CEDAR
      PP          PONDEROSA PINE
      DF          DOUGLAS FIR
      WH          WESTERN HEMLOCK

 ENTER SPECIES CODE.
>ES

 ENTER CROWN CLASS AS:
   1. DOMINANT
   2. INTERMEDIATE

 ENTER 1 OR 2
>1

 ENTER AVERAGE DBH (INCHES) FOR THIS SPECIES.

 RANGE = 1 TO 100
>24

 ENTER 10 HR LOAD (TONS PER ACRE) FOR THIS SPECIES.
 RANGE = .01 TO 30
>1.5
```

Entry of 10 hour load by species

```
IS THIS THE LAST SPECIES YOU ARE GOING TO ENTER? (Y OR N)
>N

ENTER SPECIES CODE.
>WL

ENTER CROWN CLASS AS:
   1. DOMINANT
   2. INTERMEDIATE

ENTER 1 OR 2
>2

INTERMEDIATE CROWN CLASS DATA NOT AVAILABLE FOR THIS
SPECIES. DATA FOR DOMINANT CROWN CLASS WILL BE USED.

ENTER AVERAGE DBH (INCHES) FOR THIS SPECIES.

RANGE = 1 TO 100
>20

ENTER 10 HR LOAD (TONS PER ACRE) FOR THIS SPECIES.
RANGE = .01 TO 30
>.85

IS THIS THE LAST SPECIES YOU ARE GOING TO ENTER? (Y OR N)
>Y

YOU CAN EITHER:
1. USE COMPUTER ADJUSTMENTS FOR FOLIAGE AND TWIG RETENTION
2. USE YOUR ESTIMATES OF FOLIAGE AND TWIG RETENTION
ENTER 1 OR 2
>1

WHAT PERCENT OF THE AREA IS COVERED BY SLASH?
RANGE = 0 TO 100
>60

SLASH LOADS (T/A)
1 HR       1.03
10 HR      1.41
100 HR     1.69

SLASH DEPTH  0.39 FEET

DO YOU WANT TO:
   1. ACCEPT THESE VALUES
   2. START THE SLASH SECTION ALL OVER?

ENTER 1 OR 2
>2
```

Entry of 10 hour load by species

```
SLASH SECTION.  YOU CAN:
   1. INPUT YOUR INVENTORIED DATA ON LOAD BY SIZE CLASS, AND DEPTH

   2. USE RELATIONSHIPS DEVELOPED FROM RESEARCH DATA FOR
      INTERMOUNTAIN CONIFERS. ** CAUTION ** THESE RELATIONSHIPS
      ARE PROBABLY NOT VALID WEST OF THE CASCADES OR EAST OF
      THE ROCKY MOUNTAINS.

 ENTER 1 OR 2
>2

 WHICH BEST DESCRIBES THE ORIGIN OF THE SLASH?
   1. COMMERCIAL TIMBER CUT, HIGHLEAD SKIDDING
   2. COMMERCIAL TIMBER CUT, GROUNDLEAD SKIDDING
   3. PRECOMMERCIAL THINNING.

 ENTER 1, 2, OR 3
>2

 ENTER SLASH AGE IN YEARS.
 RANGE = 0 TO 5
>3

 TO PROCEED FURTHER YOU MUST HAVE FUEL INFORMATION IN
 ONE OF FOUR FORMATS, OR ELSE END CONSIDERATION OF SLASH.
   1. TOTAL SLASH LOAD IN TONS PER ACRE
   2. LOAD OF 10 HR FUELS ONLY, IN TONS PER ACRE
   3. 10 HR LOAD IN TONS PER ACRE, BY SPECIES
   4. NUMBER OF 10 HR INTERCEPTS PER FOOT, BY SPECIES
   5. END SLASH INPUTS, PROPER DATA UNAVAILABLE

 ENTER 1, 2, 3, 4, OR 5
>4

 FOR EACH SPECIES YOU FEEL CONTRIBUTES SIGNIFICANTLY TO
 THE SLASH LOAD, YOU WILL BE ASKED ITS PRE-HARVEST AVERAGE
 CROWN CLASS (DOMINANT OR INTERMEDIATE), AVERAGE DBH, AND
 NUMBER OF 10 HR INTERCEPTS PER FOOT.

 FUEL MODELING ASSISTANCE IS AVAILABLE FOR THESE SPECIES:

 SPECIES CODE       SPECIES NAME
 ------------     ----------------

      GF          GRAND FIR
      WL          WESTERN LARCH
      ES          ENGELMANN SPRUCE
      AF          SUBALPINE FIR
      LP          LODGEPOLE PINE
      WP          WESTERN WHITE PINE
      WB          WHITEBARK PINE
      WC          WESTERN RED CEDAR
      PP          PONDEROSA PINE
      DF          DOUGLAS FIR
      WH          WESTERN HEMLOCK

 ENTER SPECIES CODE.
>WL
```

Entry of 10 hour intercepts per foot, by species

```
ENTER CROWN CLASS AS:
   1. DOMINANT
   2. INTERMEDIATE

ENTER 1 OR 2
>1

ENTER AVERAGE DBH (INCHES) FOR THIS SPECIES.

RANGE = 1 TO 100
>28

ENTER AVERAGE NUMBER OF 10 HR INTERCEPTS PER FOOT FOR
THIS SPECIES.
RANGE = .001 TO 10
>4.3

IS THIS THE LAST SPECIES YOU ARE GOING TO ENTER? (Y OR N)
>N

ENTER SPECIES CODE.
>DF

ENTER CROWN CLASS AS:
   1. DOMINANT
   2. INTERMEDIATE

ENTER 1 OR 2
>2

ENTER AVERAGE DBH (INCHES) FOR THIS SPECIES.

RANGE = 1 TO 100
>20

ENTER AVERAGE NUMBER OF 10 HR INTERCEPTS PER FOOT FOR
THIS SPECIES.
RANGE = .001 TO 10
>1.2

IS THIS THE LAST SPECIES YOU ARE GOING TO ENTER? (Y OR N)
>Y

YOU CAN EITHER:
1. USE COMPUTER ADJUSTMENTS FOR FOLIAGE AND TWIG RETENTION
2. USE YOUR ESTIMATES OF FOLIAGE AND TWIG RETENTION
ENTER 1 OR 2
>1

WHAT PERCENT OF THE AREA IS COVERED BY SLASH?
RANGE = 0 TO 100
>50

SLASH LOADS (T/A)
1 HR      2.53
10 HR     5.98
100 HR    6.28

SLASH DEPTH  0.64 FEET
```

Entry of 10 hour intercepts per foot, by species

```
DO YOU WANT TO:
   1. ACCEPT THESE VALUES
   2. START THE SLASH SECTION ALL OVER?

ENTER 1 OR 2
>1

CONTROL SECTION. KEYWORD?
>SURF

SURFACE TO VOLUME RATIO SECTION.
TYPICAL SURFACE TO VOLUME RANGES FOR VARIOUS FUEL COMPONENTS ARE:
   1 HR FUELS     (REDUCE VALUES ABOUT 200 FOR LIVE FOLIAGE)
 ------------------
 COARSE 1500-2000
 MEDIUM 2000-2500
 FINE   2500-3000

SURFACE TO VOLUME RATIOS USED IN THE 13 NFFL MODELS ARE:
 MODEL  1 HR S/V  LIVE S/V       MODEL  1 HR S/V  LIVE S/V
 -----  --------  --------       -----  --------  --------
   1      3500      ----           8      2000      ----
   2      3000      1500           9      2500      ----
   3      1500      ----          10      2000      1500
   4      2000      1500          11      1500      ----
   5      2000      1500          12      1500      ----
   6      1750      ----          13      1500      ----
   7      1750      1550
REFER TO THE USERS MANUAL IF MORE DETAILED S/V DATA IS NEEDED.

USING THE ABOVE GUIDES, ENTER A SURFACE TO VOLUME RATIO FOR:

DEAD GRASS?
RANGE = 192 TO 3500
>2500

1 HR LITTER FUELS?
>1900

1 HR SLASH FUELS?
>1500

1 HR SHRUB FUELS?
>1750

S/V RATIOS FOR LIVE FUELS SHOULD BE ABOUT 200 LESS
THAN COMPARABLE DEAD FUELS.

LIVE HERBACEOUS S/V RATIO?
>1500

LIVE WOODY S/V RATIO?
>800

YOUR S/V RATIOS ARE:  1 HR 1923.  LIVE HERB 1500.  LIVE WOODY  800
```

Entry of surface area to volume ratios

```
 DO YOU WANT TO:
   1. ACCEPT THESE VALUES
   2. REENTER THESE VALUES
   3. START THIS SECTION ALL OVER?
 ENTER 1, 2, OR 3
>1

 ENTER KEYWORD 'HEAT'

 CONTROL SECTION. KEYWORD?
>HEAT

 HEAT CONTENT SECTION

 TYPICAL HEAT CONTENT RANGES FOR VARIOUS FUEL TYPES ARE:
 LOW VOLATILE FUELS     7400-8400 (SOLID WOOD, MOST GRASSES
                                   AND HARDWOOD LEAVES)
 HIGHLY VOLATILE FUELS 8400-9400 (CONIFER FOLIAGE, SAGEBRUSH,
                                   CHAPARRAL, GALBERRY)

 8000 BTU/LB IS USED FOR ALL LIVE AND DEAD FUELS IN THE 13 NFFL MODELS

 USE THE LOW END OF THE RANGE FOR FUEL THAT DOES NOT PRODUCE
 VOLATILES THAT CAN BE SMELLED ON HOT DAYS (MOST DEAD FUELS)
 THE HIGH END FOR FUELS THAT DO, OR THAT FEEL OILY OR WAXY.
 (EX: SOME LIVE FUELS SUCH AS GALLBERRY LEAVES OR PINE NEEDLES)

 ENTER HEAT CONTENT FOR DEAD FUELS
 RANGE = 7000 TO 10000
>8500

 ENTER HEAT CONTENT FOR LIVE HERBACEOUS FUELS
 RANGE = 7000 TO 10000
>8000

 ENTER HEAT CONTENT FOR LEAVES AND TWIGS OF LIVE SHRUBS
 RANGE = 7000 TO 10000
>8000

 YOUR WEIGHTED AVERAGE HEAT CONTENT (BTU/LB) IS 8440.
 DO YOU WANT TO:
   1. ACCEPT THIS VALUE
   2. START THIS SECTION OVER?
 ENTER 1 OR 2
>1
```

Entry of heat contents

```
CONTROL SECTION, KEYWORD?
>COMP

      LOADS, S/V RATIOS, AND DEPTHS FOR INDIVIDUAL FUEL COMPONENTS

   FUEL
COMPONENT ************* LOADS *************  *** S/V RATIOS ****   DEPTHS
           1 HR   10 HR   100 H    HERB   WOODY  1 HR    HERB    WOODY
LITTER     5.40    1.01    0.34    0.00    0.00  1900.      0.       0.   0.25
GRASS      1.47    0.00    0.00    1.47    0.00  2500.   1500.       0.   1.80
SHRUBS     0.90    1.20    0.30    0.00    0.60  1750.      0.     800.   2.00
SLASH      2.53    5.98    6.28    0.00    0.00  1500.      0.       0.   0.44

************** FUEL LOAD SUMMARY *************
**** FUEL COMPONENT ****      ** TIMELAG CLASS *
*         DEAD    LIVE  *     *                *
*         ----    ----  *     * CLASS     LOAD *
* LITTER   6.75    0.00 *     * -----     ---- *
* GRASS    1.47    1.47 *     * 1 HR     10.30 *
* SHRUBS   2.40    0.60 *     * 10 HR     8.19 *
* SLASH   14.78    0.00 *     * 100 HR    6.92 *
*         -----   ----- *     *          ----- *
* TOTAL   25.40    2.07 *     * TOTAL    25.40 *

CONTROL SECTION, KEYWORD?
>MODEL

                 CURRENT VALUES OF FUEL MODEL PARAMETERS
DYNAMIC 60, FIRST SAMPLE MODEL                  BY: BURGAN

      LOAD (T/AC)           S/V RATIOS                   OTHER
  -------------------   -------------------   -----------------------------
  1 HR          10.30   1 HR          1923.   DEPTH (FEET)              0.81
  10 HR          8.19   LIVE HERB     1500.   HEAT CONTENT (BTU/LB)    8440.
  100 HR         6.92   LIVE WOODY     800.   EXT MOISTURE (%)           13.
  LIVE HERB      1.47   S/V = (SQFT/CUFT)
  LIVE WOODY     0.60
```

Data for all fuel components

Completed fuel model

```
 CONTROL SECTION, KEYWORD?
>FILE

 ENTER THE NAME OF YOUR FUEL MODEL FILE.
>MYFILE

 THIS WILL BE A NEW FILE. OK? (Y OR N).
>Y
 YOU NEED TO CREATE A HEADER FOR THIS FUEL FILE

 ENTER FUEL MODEL FILE PASSWORD (4 CHAR MAX)
  ----
>NFFL

 ENTER COMMENT TO DESCRIBE THIS FUEL FILE (72 CHAR MAX)
 ------------------------------------------------------------------------
>SAMPLE FUEL MODEL FILE

 DO YOU WANT TO:
   1) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
   2) CHANGE A FUEL FILE HEADER
   3) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
   4) REPLACE A FUEL MODEL IN THE FILE
   5) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
   6) GO BACK TO THE CONTROL SECTION

  ENTER 1, 2, 3, 4, 5, OR 6
 >3

  ENTER PASSWORD
 >NFFL
  FUEL MODEL 60 WRITTEN TO FUEL MODEL FILE

  DO YOU WANT TO:
    1) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
    2) CHANGE A FUEL FILE HEADER
    3) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
    4) REPLACE A FUEL MODEL IN THE FILE
    5) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
    6) GO BACK TO THE CONTROL SECTION

  ENTER 1, 2, 3, 4, 5, OR 6
 >6
```

Adding the fuel model to the file

```
CONTROL SECTION, KEYWORD?
>RESTART


WELCOME TO THE
   BEHAVE SYSTEM
      FUEL SUBSYSTEM
         NEWMDL PROGRAM (VERSION 2.0 -- AUGUST 1983)

DEVELOPED BY THE
   FIRE BEHAVIOR RESEARCH WORK UNIT
   NORTHERN FOREST FIRE LABORATORY
   MISSOULA,MONTANA

ENTER YOUR LAST NAME.
>BURGAN

THE OBJECTIVE OF THIS PROGRAM IS TO HELP YOU DEVELOP
A FIRE BEHAVIOR FUEL MODEL THAT REASONABLY CHARACTERIZES A
FUEL COMPLEX NOT PROPERLY REPRESENTED BY ONE OF THE THIRTEEN
NFFL FUEL MODELS.

A TERSE MODE IS AVAILABLE FOR EXPERIENCED USERS
THAT WANT LIMITED PROMPTING.  DO YOU WANT TERSE? (Y OR N).
>N

FULL PROMPT MODE SET.

PROGRAM CONTROL IS THROUGH THE USE OF KEYWORDS.
DO YOU WANT A LIST OF KEYWORDS AND THEIR FUNCTIONS? (Y OR N)
>N

A FUEL MODEL MAY BE CONSTRUCTED WITH EITHER
    1.  1 SIZE OF FINE FUEL IN ONE OR MORE COMPONENTS
    2.  2 SIZES OF FINE FUEL IN ONE OR MORE COMPONENTS

ENTER 1 OR 2
>2

ENTER A NUMBER FOR YOUR PROPOSED FUEL MODEL.
RANGE = 14 TO 99
>61

ENTER FUEL MODEL NAME (32 CHARACTERS MAXIMUM).
--------------------------------
>SECOND SAMPLE MODEL

EXPANDED FINE FUEL INPUT SECTION.
THIS SECTION PROVIDES FOR DIRECT ENTRY OF TWO 1 HR LOADS
AND S/V RATIOS IN LITTER, SHRUB, SLASH, AND GRASS
FUELS.  10 HR, 100 HR AND LIVE LOADS ARE ALSO ENTERED.
THE MULTIPLE 1 HR LOADS ARE ADJUSTED TO PROVIDE
A SINGLE REPRESENTATIVE LOAD AND S/V RATIO.
```

Start again at the beginning of the program

Building a fuel model with two sizes of fine fuel

```
DO YOU WANT TO ENTER ANY LITTER LOAD? (Y OR N)
>N

DO YOU WANT TO ENTER ANY SLASH LOADS? (Y OR N)
>Y
ENTER FIRST LOAD.
RANGE = 0 TO 30 TONS PER ACRE.
>2
ENTER FIRST S/V RATIO.
RANGE = 192 TO 3500
>2000
ENTER SECOND LOAD.
RANGE = 0 TO 30 TONS PER ACRE.
>3
ENTER SECOND S/V RATIO.
RANGE = 192 TO 3500
>1000

ENTER 10 HR LOAD
RANGE = 0 TO 30 TONS PER ACRE.
>5

ENTER 100 HR LOAD
RANGE = 0 TO 30 TONS PER ACRE.
>9

SLASH DEPTH IN FEET?
RANGE = 0 TO 10
>1

WHAT PERCENT OF THE AREA IS COVERED BY SLASH?
RANGE = 0 TO 100
>80

 YOUR SLASH ENTRIES, REDUCED FOR AREA COVERAGE ARE:
1 HRTL FUELS   LOADS   S/V RATIOS
FIRST ENTRY     1.60     2000.
SECOND ENTRY    2.40     1000.
1 HR LOAD      4.00
10 HR LOAD     4.00
100 HR LOAD     7.20
DEPTH (FEET)  0.80
PERCENT AREA COVERED   80.

DO YOU WANT TO:
1  ACCEPT THESE ENTRIES
2  REENTER THIS DATA
ENTER 1 OR 2
>1

DO YOU WANT TO ENTER ANY SHRUB LOAD? (Y OR N)
>N

DO YOU WANT TO ENTER ANY GRASS LOAD? (Y OR N)
>N
```

Building a fuel model with two sizes of fine fuel

```
HEAT CONTENT SECTION

TYPICAL HEAT CONTENT RANGES FOR VARIOUS FUEL TYPES ARE:
LOW VOLATILE FUELS     7400-8400 (SOLID WOOD, MOST GRASSES
                                   AND HARDWOOD LEAVES)
HIGHLY VOLATILE FUELS 8400-9400 (CONIFER FOLIAGE, SAGEBRUSH,
                                   CHAPARRAL, GALBERRY)

8000 BTU/LB IS USED FOR ALL LIVE AND DEAD FUELS IN THE 13 NFFL MODELS

USE THE LOW END OF THE RANGE FOR FUEL THAT DOES NOT PRODUCE
VOLATILES THAT CAN BE SMELLED ON HOT DAYS (MOST DEAD FUELS)
THE HIGH END FOR FUELS THAT DO, OR THAT FEEL OILY OR WAXY.
(EX: SOME LIVE FUELS SUCH AS GALLBERRY LEAVES OR PINE NEEDLES)

ENTER HEAT CONTENT FOR DEAD FUELS
RANGE = 7000 TO 10000
>8000

YOUR WEIGHTED AVERAGE HEAT CONTENT (BTU/LB) IS 8000.
DO YOU WANT TO:
   1. ACCEPT THIS VALUE
   2. START THIS SECTION OVER?
ENTER 1 OR 2
>1

                CURRENT VALUES OF FUEL MODEL PARAMETERS
STATIC 61. SECOND SAMPLE MODEL                  BY: BURGAN

      LOAD (T/AC)           S/V RATIOS                   OTHER
   ------------------    -----------------    ------------------------------

   1 HR          1.62    1 HR        1728.    DEPTH (FEET)            0.47
   10 HR         4.00    LIVE HERB      0.    HEAT CONTENT (BTU/LB)  8000.
   100 HR        7.20    LIVE WOODY     0.    EXT MOISTURE (%)         28.
   LIVE HERB     0.00    S/V = (SQFT/CUFT)
   LIVE WOODY    0.00

DO YOU WANT TO:
   1. START ALL OVER
   2. FILE YOUR FUEL MODEL
   3. RENUMBER YOUR FUEL MODEL
   4. QUIT THIS SESSION

ENTER 1, 2, 3 OR 4
>2
```

Building a model with two sizes of fine fuel

```
 DO YOU WISH TO USE THE CURRENT FUEL MODEL FILE (Y OR N)?
 THE CURRENT FILE IS MYFILE
>Y

 DO YOU WANT TO:
   1) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
   2) CHANGE A FUEL FILE HEADER
   3) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
   4) REPLACE A FUEL MODEL IN THE FILE
   5) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
   6) GO BACK TO THE CONTROL SECTION

 ENTER 1, 2, 3, 4, 5, OR 6
>3

 ENTER PASSWORD
>NFFL
 FUEL MODEL 61 WRITTEN TO FUEL MODEL FILE

 DO YOU WANT TO:
   1) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
   2) CHANGE A FUEL FILE HEADER
   3) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
   4) REPLACE A FUEL MODEL IN THE FILE
   5) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
   6) GO BACK TO THE CONTROL SECTION

 ENTER 1, 2, 3, 4, 5, OR 6
>6

 DO YOU WANT TO:
   1. START ALL OVER
   2. FILE YOUR FUEL MODEL
   3. RENUMBER YOUR FUEL MODEL
   4. QUIT THIS SESSION

 ENTER 1, 2, 3 OR 4
>4

 DO YOU REALLY WANT TO TERMINATE THIS RUN? (Y OR N).
>Y


 NEWMDL RUN TERMINATED.
 ******************************
```

Filing the model with two sizes of fine fuels

APPENDIX C: EXAMPLE TSTMDL SESSION

This TSTMDL session provides brief examples of most of the capabilities of this program. It illustrates how to manipulate fuels and environmental data, obtain graphic and tabular output, use both the normal and technical versions, manipulate the fuel model file, and obtain a fuel data listing for the TI-59.

Although the session can be duplicated as presented, it is structured for easy reference to specific activities such as changing values of fuel model parameters, doing technical version graphics, etc.

Lines that begin with a prompt character (>) were typed by the user. All other lines were printed by the computer.

```
[illegible]

WELCOME TO THE
  BEHAVE SYSTEM
    FUEL SUBSYSTEM
      TSTMDL PROGRAM (VERSION 2.2 -- SEPTEMBER 1983)

DEVELOPED BY THE
  FIRE BEHAVIOR RESEARCH WORK UNIT
  NORTHERN FOREST FIRE LABORATORY
  MISSOULA,MONTANA

ENTER YOUR LAST NAME.
>BURGAN

ARE YOU USING A TERMINAL WITH A SCREEN?  (Y OR N).
>Y

THE INTERACTIVE FUEL MODEL TESTING PROGRAM HAS BOTH A
'NORMAL' AND A 'TECHNICAL' VERSION.  THE NORMAL VERSION
SHOULD BE USED FIRST, BUT IF YOU WANT MORE DETAIL THE
TECHNICAL VERSION PERMITS GRAPHIC OR TABULAR DISPLAY OF
ADDITIONAL FUEL AND FIRE MODEL PARAMETERS.

A 'TERSE' MODE IS AVAILABLE FOR EXPERIENCED USERS
THAT WANT LIMITED PROMPTING.  DO YOU WANT TERSE? (Y OR N).
>N

FULL PROMPT MODE SET.

WILL YOU BE:
  1. CREATING A NEW FUEL MODEL OR USING AN NFFL FUEL MODEL?
  2. LOADING A PREVIOUSLY BUILT MODEL FROM A FUEL MODEL FILE?
ENTER 1 OR 2
>1

ENTER THE NUMBER YOU WANT ASSIGNED TO THIS CUSTOM MODEL
RANGE = 14 TO 99
>59

ENTER FUEL MODEL NAME (32 CHARACTERS MAXIMUM).
................................
>DUMMY MODEL

IS YOUR PROPOSED FUEL MODEL DYNAMIC(1) OR STATIC(2)?

DYNAMIC MODELS ADJUST FOR SEASONAL DRYING THROUGH TRANSFER
OF LIVE HERBACEOUS LOAD BETWEEN LIVE HERBACEOUS AND 1 HOUR
TIMELAG CLASSES, AS A FUNCTION OF HERBACEOUS FUEL MOISTURE.

STATIC MODELS HAVE CONSTANT LOADS IN ALL LIVE AND DEAD
FUEL CLASSES.
ENTER 1 OR 2
>1
```

Start of session

```
 PROGRAM CONTROL IS THROUGH THE USE OF KEYWORDS.
 DO YOU WANT A LIST OF KEYWORDS AND THEIR FUNCTIONS? (Y OR N)
>Y
 THE PRIMARY KEYWORDS AND THEIR FUNCTIONS ARE:
   KEYWORD              FUNCTION
     KEY       PRINTS THIS KEYWORD LIST
     TERSE     SET TERSE MODE FOR MINIMAL PROMPTING
     WORDY     SET WORDY MODE FOR FULL PROMPTING
     NORM      IMPLEMENTS 'NORMAL' VERSION OF PROGRAM
     TECH      IMPLEMENTS 'TECHNICAL' VERSION OF PROGRAM
     FUEL      ENTER NEW OR CHANGE EXISTING FUEL MODEL DATA
     ENV       ENTER NEW OR CHANGE EXISTING ENVIRONMENTAL DATA
     GRAPH     IMPLEMENTS GRAPHIC OUTPUT OF COMPUTED RESULTS
     TABLE     IMPLEMENTS TABULAR OUTPUT OF COMPUTED RESULTS
     RENUMBER  RENUMBER FUEL MODEL AND SELECT DYNAMIC OR STATIC
     RESTART   START PROGRAM AT BEGINNING AGAIN
     FILE      ACCESS FUEL MODEL FILE
     TI59      LIST DATA FOR TI59 FUEL MODEL CARD
     QUIT      QUIT SESSION

 WHENEVER 'KEYWORD?' IS PRINTED, TYPE THE KEYWORD FOR
 THE NEXT TASK YOU WANT TO ACCOMPLISH.  YOUR FIRST RESPONSE
 SHOULD BE THE KEYWORD 'NORM' OR 'TECH' TO GET THE VERSION
 YOU WANT.
 CONTROL SECTION, KEYWORD?
>NORM

 NORMAL VERSION SET.
```

Start of session

```
ENTER KEYWORD 'FUEL' TO DEFINE FUEL MODEL PARAMETERS.
CONTROL SECTION. KEYWORD?
FUEL

FUELS MANIPULATION SECTION.
   TO USE ONE OF THE 13 NFFL FUEL MODELS TYPE 'NFFL'.
   TO INPUT ALL FUELS DATA TYPE 'NEW'.
   TO CHANGE EXISTING FUELS DATA TYPE 'CHANGE'.
   TO LIST CURRENT FUELS DATA TYPE 'LIST'.
   TO GET OUT OF THE FUELS SECTION TYPE 'QUIT'.

KEYWORD?
>NEW

NEW FUEL MODEL DATA INPUT SECTION.
FUELS DATA:
     FUEL LOAD (TONS/ACRE):
         RANGE = 0. TO 30.

          1 HR?
>2

          10 HR?
>2.5

          100 HR?
>1

          LIVE HERB?
>.8

          LIVE WOODY?
>1.4

FUEL BED DEPTH IN FEET?
RANGE = .01 TO 10.
>1.7

HEAT CONTENT IN BTU/LB?
RANGE = 7000. TO 12000.
>8000

MOISTURE OF EXTINCTION?
RANGE = 10. TO 60.
>20

     SURFACE AREA/VOLUME RATIOS (SQ FT/CU FT):
         RANGE = 192. TO 3500.

          1 HR S/V?
>2000

          LIVE HERB S/V?
>1800

          LIVE WOODY S/V?
>1600
```

This is a good way to enter fuel model data if you know exactly what the values are.

For example you could re-enter the data for a model that was accidently deleted from your fuel model file.

Entering fuel model data directly

```
FUELS MANIPULATION SECTION.
TYPE 'NFFL', 'NEW', 'CHANGE', 'LIST', OR 'QUIT'.

KEYWORD?
>LIST

               CURRENT VALUES OF FUEL MODEL PARAMETERS
DYNAMIC 59. DUMMY MODEL                          BY: BURGAN

      LOAD (T/AC)           S/V RATIOS                 OTHER
   -----------------    ------------------    ----------------------
   1 HR          2.00   1 HR         2000.    DEPTH                1.70
   10 HR         2.50   LIVE HERB    1300.    HEAT CONTENT      8000.
   100 HR        1.00   LIVE WOODY   1600.    EXT MOISTURE        20.
   LIVE HERB     0.80
   LIVE WOODY    1.40

FUELS MANIPULATION SECTION.
TYPE 'NFFL', 'NEW', 'CHANGE', 'LIST', OR 'QUIT'.

KEYWORD?
>NFFL

THIS WILL PLACE AN NFFL MODEL IN COMPUTER MEMORY
IF YOU NOW HAVE A MODEL IN MEMORY, IT WILL BE WIPED OUT
THIS WILL NOT AFFECT YOUR FUEL MODEL FILE.

ENTER YES IF THIS IS OK
ENTER NO IF YOU NEED TO STOP AND FILE YOUR CURRENT MODEL.
>YES

ENTER NFFL MODEL NUMBER (RANGE = 1 TO 13)
>3

NFFL MODEL  3 ENTERED.

ALL NFFL MODELS ARE STATIC. IF YOU WANT TO PRODUCE A DYNAMIC
MODEL USEING THE PARAMETERS OF THIS MODEL  TYPE 'LIST', THEN
'NEW' AND ENTER THE PARAMETERS OF THIS NFFL MODEL.

FUELS MANIPULATION SECTION.
TYPE 'NFFL', 'NEW', 'CHANGE', 'LIST', OR 'QUIT'.

KEYWORD?
>LIST

               CURRENT VALUES OF FUEL MODEL PARAMETERS
STATIC 59. DUMMY MODEL                           BY: BURGAN

      LOAD (T/AC)           S/V RATIOS                 OTHER
   -----------------    ------------------    ----------------------
   1 HR          3.01   1 HR         1500.    DEPTH                2.50
   10 HR         0.00   LIVE HERB       0.    HEAT CONTENT      6000.
   100 HR        0.00   LIVE WOODY      0.    EXT MOISTURE        25.
   LIVE HERB     0.00
   LIVE WOODY    0.00
```

Listing the fuel model

Getting an NFFL model

```
FUELS MANIPULATION SECTION.
TYPE 'NEW', 'OLD', 'CHANGE', 'LIST' OR 'QUIT'.

KEYWORD?
>CHANGE

FUEL MODIFICATION SECTION.
ENTER KEYWORD 'QUIT' AFTER LAST CHANGE.

DO YOU WANT A LIST OF FUEL MODEL KEYWORDS? (Y OR N)
>Y

THE FUEL MODEL KEYWORDS AND THEIR MEANINGS ARE:
  KEYWORD        MEANING
    KEY     PRINT THIS KEYWORD KEY
    SA1     1 HR S/V RATIO
    SAH     HERB S/V RATIO
    SAW     WOODY S/V RATIO
    DEPTH   FUEL BED DEPTH
    HEAT    HEAT CONTENT
    EXTM    EXTINCTION MOISTURE
    L1      1 HR FUEL LOAD
    L10     10 HR FUEL LOAD
    L100    100 HR FUEL LOAD
    LH      HERB LOAD
    LW      WOODY LOAD
    QUIT    STOP MAKING FUEL MODEL CHANGES

KEYWORD?
>EXTM

MOISTURE OF EXTINCTION?
RANGE = 10. TO 60.
>20

KEYWORD?
>SA1

1 HR S/V RATIO?
RANGE = 192. TO 3500.
>1500

KEYWORD?
>QUIT

FUELS MANIPULATION SECTION.
TYPE 'NEW', 'OLD', 'CHANGE', 'LIST' OR 'QUIT'

KEYWORD?
>LIST

                 CURRENT VALUES OF FUEL MODEL PARAMETERS
[illegible] MODEL                                  BY: BURGAN

         LOAD (T/AC)           S/V RATIOS              OTHER
     ----------------------  -------------------  ----------------------
     1 HR          3.01    1 HR        1500.    DEPTH             2.50
     10 HR         0.00    LIVE HERB      0.    HEAT CONTENT   3000.
     100 HR        0.00    LIVE WOODY     0.    EXT MOISTURE     20.
     LIVE HERB     0.00
     LIVE WOODY    0.00
```

While any of the items in the above list can be changed, only extinction moisture and 1 hour S/V ratio were.

Changing the fuel model

```
FUELS MANIPULATION SECTION.
TYPE 'NFFL', 'NEW', 'CHANGE', 'LIST', OR 'QUIT'.

KEYWORD?
>QUIT
```

This is just a reminder printed by the 'wordy' mode. You will eventually have to do this, but you don't have to do it now.

```
ENTER KEYWORD 'ENV' TO DEFINE ENVIRONMENTAL PARAMETERS.
CONTROL SECTION. KEYWORD?
>FILE

ENTER THE NAME OF YOUR FUEL MODEL FILE.
>MYFILE

DO YOU WANT TO:
  1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
  2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
  3) CHANGE A FUEL FILE HEADER
  4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
  5) REPLACE A FUEL MODEL IN THE FILE
  6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
  7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7
>1

ENTER FUEL MODEL NUMBER
RANGE = 14 TO 99
>60

MODEL 60 LOADED
```

Again this reminder, but I wanted to list the fuel model first.

Getting a fuel model from your file.

```
ENTER KEYWORD 'ENV' TO DEFINE ENVIRONMENTAL PARAMETERS.
CONTROL SECTION. KEYWORD?
>FUEL

FUELS MANIPULATION SECTION.
  TO USE ONE OF THE 13 NFFL FUEL MODELS TYPE 'NFFL'.
  TO INPUT ALL FUELS DATA TYPE 'NEW'.
  TO CHANGE EXISTING FUELS DATA TYPE 'CHANGE'.
  TO LIST CURRENT FUELS DATA TYPE 'LIST'.
  TO GET OUT OF THE FUELS SECTION TYPE 'QUIT'.

KEYWORD?
>LIST

              CURRENT VALUES OF FUEL MODEL PARAMETERS
DYNAMIC 60, FIRST SAMPLE MODEL                    BY: BURGAN

     LOAD (T/AC)            S/V RATIOS                  OTHER
   ----------------      -----------------      ----------------------
   1 HR         10.30    1 HR          1923.    DEPTH                0.81
   10 HR         8.19    LIVE HERB     1500.    HEAT CONTENT      8440.
   100 HR        6.92    LIVE WOODY     800.    EXT MOISTURE        13.
   LIVE HERB     1.47
   LIVE WOODY    0.60
```

```
FUEL MANIPULATION SECTION.
TYPE 'MODEL', 'NEW', 'CHANGE', 'LIST', OR 'QUIT'.

KEYWORD?
>QUIT

ENTER KEYWORD 'ENV' TO DEFINE ENVIRONMENTAL PARAMETERS.
CONTROL SECTION. KEYWORD?
>ENV

ENVIRONMENT MANIPULATION SECTION.
  TO INPUT ALL ENVIRONMENTAL DATA TYPE 'NEW'.
  TO CHANGE EXISTING ENVIRONMENTAL DATA TYPE 'CHANGE'.
  TO LIST CURRENT ENVIRONMENTAL DATA TYPE 'LIST'.
  TO ASSIGN STANDARD ENVIRONMENTAL DATA TYPE 'STD'.
  TO GET OUT OF THE ENVIRONMENTAL SECTION TYPE 'QUIT'.

KEYWORD?
>STD

    FUEL CLASS          FUEL MOISTURES                    OTHER
    ----------    ----------------------------   --------------------------
                  LOW        MED        HIGH
     1 HR          3.         6.         12.     MIDFLAME WINDSPEED
     10 HR         4.         7.         13.            4 MPH
     100 HR        5.         8.         14.
     LIVE HERB    70.       120.        170.     SLOPE = 30. PERCENT
     LIVE WOODY   70.       120.        170.
ENTER 'LOW', OR 'MEDIUM', OR 'HIGH' TO SELECT FUEL <- The choices
MOISTURE RANGE
>LOW <- The range selected
STANDARD ENVIRONMENTAL DATA SET.

ENVIRONMENT MANIPULATION SECTION.
TYPE 'NEW', 'CHANGE', 'LIST', 'STD', OR 'QUIT'.

KEYWORD?
>LIST
                  STANDARD ENVIRONMENTAL PARAMETERS
DYNAMIC 60. FIRST SAMPLE MODEL                     BY: BURGAN

    FUEL CLASS          FUEL MOISTURES                    OTHER
    ----------    ----------------------------   --------------------------
                  LOW        MED        HIGH
     1 HR          3.         6.         12.     MIDFLAME WINDSPEED
     10 HR         4.         7.         13.            4 MPH
     100 HR        5.         8.         14.
     LIVE HERB    70.       120.        170.     SLOPE = 30  PERCENT
     LIVE WOODY   70.       120.        170.
LOW FUEL MOISTURE SET. <- Proof that the low moisture
                          range is now set.
```

Getting standard environmental data

```
 ENVIRONMENT MANIPULATION SECTION.
 TYPE 'NEW', 'CHANGE', 'LIST', 'STD', OR 'QUIT'.

 KEYWORD?
>NEW

 NEW ENVIRONMENTAL DATA SECTION.

 ENVIRONMENTAL DATA:
      DEAD MOISTURES(%):
          RANGE = 2. TO 50.
           1 HR?
>4
           10 HR?
>5
           100 HR?
>6
      LIVE MOISTURES (%)
          RANGE = 30. TO 350.
           LIVE HERB?
>100
           LIVE WOODY?
>120
 MIDFLAME WINDSPEED IN MPH?
 RANGE = 0. TO 18.
>5
 SLOPE IN PERCENT?
 RANGE = 0. TO 200.
>30

 ENVIRONMENT MANIPULATION SECTION.
 TYPE 'NEW', 'CHANGE', 'LIST', 'STD', OR 'QUIT'.

 KEYWORD?
>LIST

          CURRENT USER DEFINED ENVIRONMENTAL PARAMETERS

DYNAMIC, 60. FIRST SAMPLE MODEL                      BY: BURGAN

            MOISTURES (%)                               OTHER
           -----------------------             ----------------------------
           1 HR           4.                   MIDFLAME WIND (MPH)      5.
           10 HR          5.                   SLOPE (PERCENT)         30.
           100 HR         6.
           LIVE HERB    100.
           LIVE WOODY   120.
```

Entering new environmental data

```
ENVIRONMENT MANIPULATION SECTION.
TYPE 'NEW', 'CHANGE', 'LIST', 'STD', OR 'QUIT'.

KEYWORD?
>CHANGE

ENVIRONMENTAL DATA MODIFICATION SECTION.

TYPE KEYWORD 'QUIT' AFTER LAST CHANGE.
DO YOU WANT A LIST OF ENVIRONMENTAL KEYWORDS? (Y OR N)
>Y

THE ENVIRONMENTAL KEYWORDS AND THEIR MEANINGS ARE:
  KEYWORD          MEANING
    KEY      PRINT THIS KEYWORD LIST
    M1       1 HR FUEL MOISTURE
    M10      10 HR FUEL MOISTURE
    M100     100 HR FUEL MOISTURE
    MHERB    LIVE HERB FUEL MOISTURE
    MWOOD    LIVE WOODY FUEL MOISTURE
    WIND     MIDFLAME WINDSPEED
    SLOPE    PERCENT SLOPE
    QUIT     STOP MAKING ENVIRONMENTAL CHANGES

KEYWORD?
>MHERB
LIVE HERB?
RANGE = 30. TO 350.
>90

KEYWORD?
>SLOPE
SLOPE IN PERCENT?
RANGE = 0. TO 200.
>35

KEYWORD?
>QUIT

ENVIRONMENT MANIPULATION SECTION.
TYPE 'NEW', 'CHANGE', 'LIST', 'STD', OR 'QUIT'.

KEYWORD?
>LIST

      CURRENT USER DEFINED ENVIRONMENTAL PARAMETERS

DYNAMIC, 60, FIRST SAMPLE MODEL                BY: BURGAN

        MOISTURES (%)                      OTHER
        -----------------           --------------------------
        1 HR            4.          MIDFLAME WIND (MPH)     5.
        10 HR           5.          SLOPE (PERCENT)        35.
        100 HR          6.
        LIVE HERB      90.
        LIVE WOODY    120.
```

Any of the items in the above list can be changed, but only live herbaceous moisture and slope were.

Changing the environmental data

```
 ENVIRONMENT MANIPULATION SECTION.
 TYPE 'NEW', 'CHANGE', 'LIST', 'STD', OR 'QUIT'.

 KEYWORD?
>QUIT

 ENTER KEYWORD 'GRAPH' OR 'TABLE' TO DEFINE TYPE OF OUTPUT.
 CONTROL SECTION. KEYWORD?
>TABLE
 TABLE OUTPUT SET.

 TABULAR OUTPUT SECTION.

 DO YOU WANT A LIST OF KEYWORDS FOR SELECTING AN ENVIRONMENTAL
 PARAMETER TO VARY? (Y OR N).
>Y

 THE KEYWORDS FOR THE ENVIRONMENTAL VARIABLES ARE:

   KEYWORD      VARIABLE
   KEY       PRINT THIS KEYWORD LIST
   M1        1 HR FUEL MOISTURE
   M10       10 HR FUEL MOISTURE
   M100      100 HR FUEL MOISTURE
   MHERB     LIVE HERB FUEL MOISTURE
   MWOOD     LIVE WOODY FUEL MOISTURE
   WIND      MIDFLAME WINDSPEED
   SLOPE     PERCENT SLOPE

 ENTER ENVIRONMENTAL PARAMETER KEYWORD.
>WIND

 YOUR MIDFLAME WINDSPEED IS    5.
 ENTER 2 MORE VALUES.

 FIRST VALUE?
 RANGE = 0. TO 18.
>0

 SECOND VALUE?
>10
```

Obtaining tabular output.

The environmental parameter selected to vary was wind. Any other item could be chosen.

FUEL MODEL TEST RUN -- USER DEFINED ENVIRONMENTAL IN PUT

DYNAMIC 60. FIRST SAMPLE MODEL BY: BURGAN

LOAD (T/AC)		S/V RATIOS		OTHER	
1 HR	10.30	1 HR	1923.	DEPTH	0.81
10 HR	8.19	LIVE HERB	1500.	HEAT CONTENT	8440.
100 HR	6.92	LIVE WOODY	800.	EXT MOISTURE	13.
LIVE HERB	1.47	SIGMA	1790.	PR/OPR	6.70
LIVE WOODY	0.60				

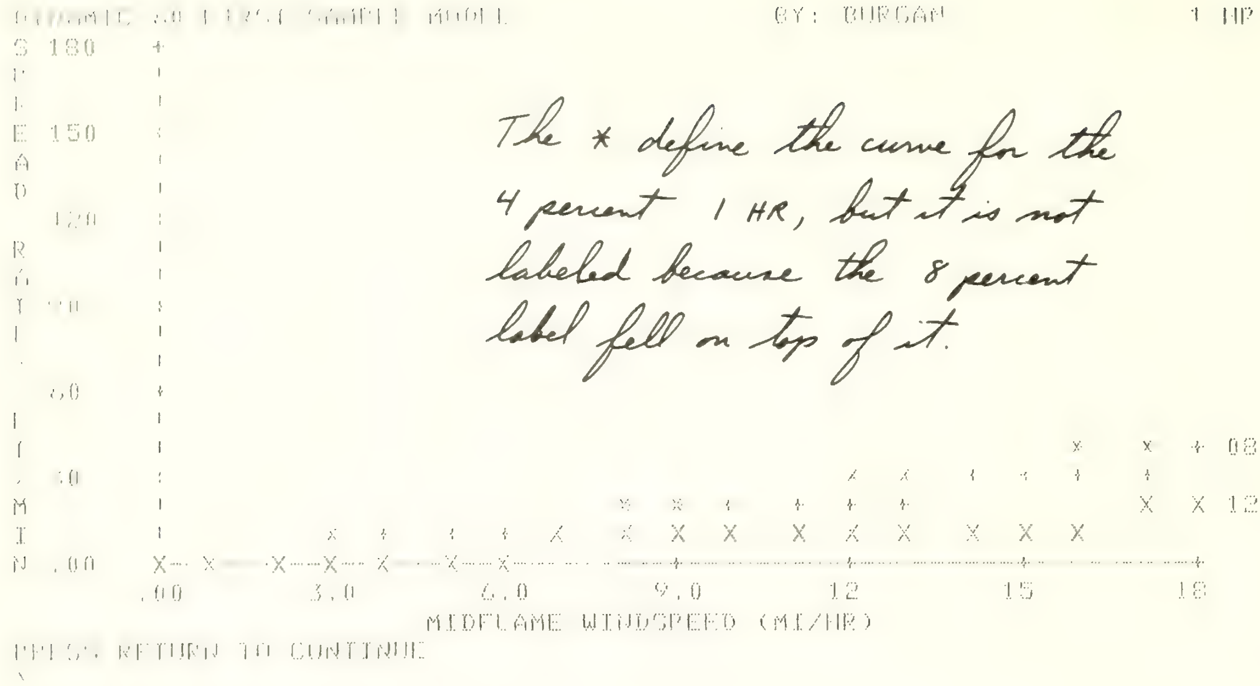
ENVIRONMENTAL DATA		FIRE BEHAVIOR RESULTS			
		FIRE VARIABLE	MIDFLAME WIND 0.	5.	10.
1 HR FM	4.	ROS (FT/M)	3.	9.	20.
10 HR FM	5.	FL (FT)	2.	4.	6.
100 HR FM	6.	IR (BTU/SQFT/M)	4212.	4212.	4212.
LIVE HERB FM	90.	H/A (BTU/SQFT)	904.	904.	904.
LIVE WOODY FM	120.	FLI (BTU/FT/SEC)	39.	137.	306.
SLOPE (%)	35.				

RUN ANOTHER TABLE? (Y OR N)
>N

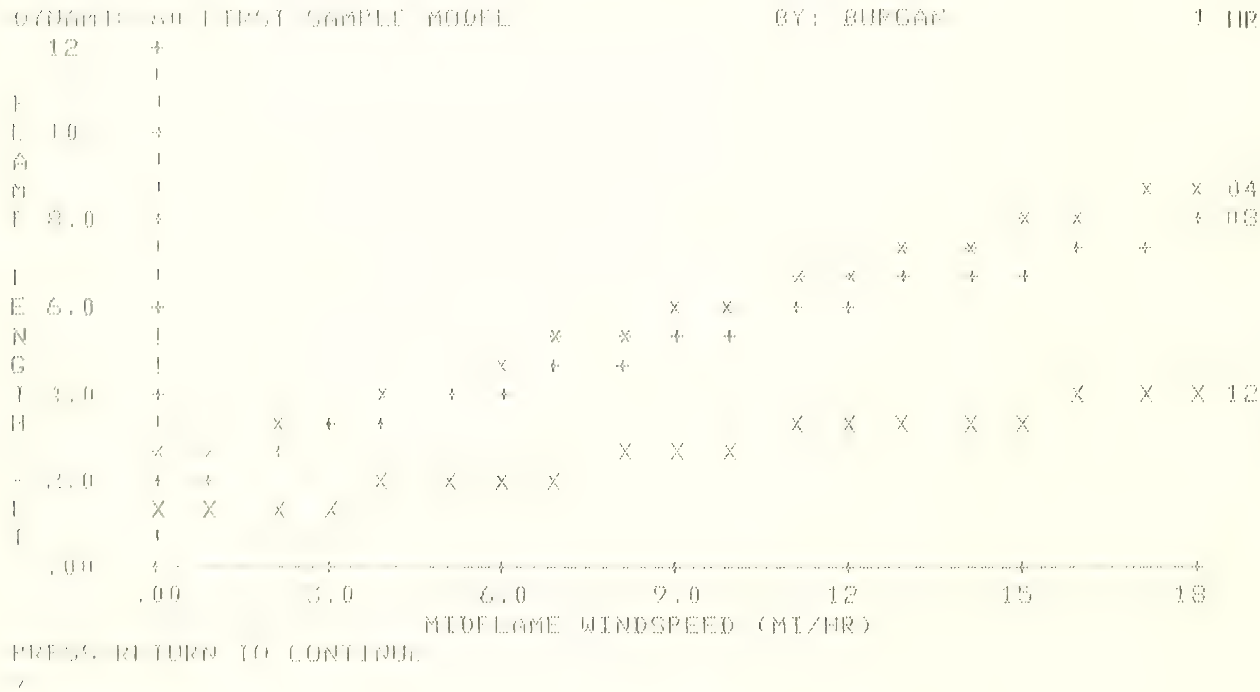
Obtaining tabular output

```
 CONTROL SECTION. KEYWORD?
>GRAPH
 GRAPHIC OUTPUT SET.

 NORMAL VERSION GRAPHICS SECTION.

 DO YOU WANT GRAPH 1 - RATE OF SPREAD? (Y OR N).
>Y

 DO YOU WANT GRAPH 2 - FLAME LENGTH? (Y OR N).
>Y

 DO YOU WANT TO USE:
   1) STANDARD
   2) CALCULATED
 SCALING OF THE Y-AXIS?

 ENTER 1 OR 2
>1

 YOUR 1 HR FM IS    4.
 DO YOU WANT TO PLOT CURVES FOR 2 MORE 1 HR MOISTURES?  (Y OR N)
>Y

 FIRST VALUE?
 RANGE = 2. TO 50.
>8

 SECOND VALUE?
 RANGE = 2. TO 50.
>12

 DO YOU WANT GRAPH 3 - FIRE CHARACTERISTICS CHART?  (Y OR N).
>Y

 DO YOU WANT TO COMPARE YOUR MODEL WITH 1 OR 2 NFFL MODELS? (Y OR N).
 >Y

 ENTER FIRST NFFL MODEL NUMBER
 RANGE = 1. TO 13.
 >8

 DO YOU WANT TO SELECT A SECOND NFFL MODEL? (Y OR N).
 >Y

 ENTER SECOND NFFL MODEL NUMBER
 RANGE = 1. TO 13.
 >9
```

obtaining graphic output, normal version, standard scaling

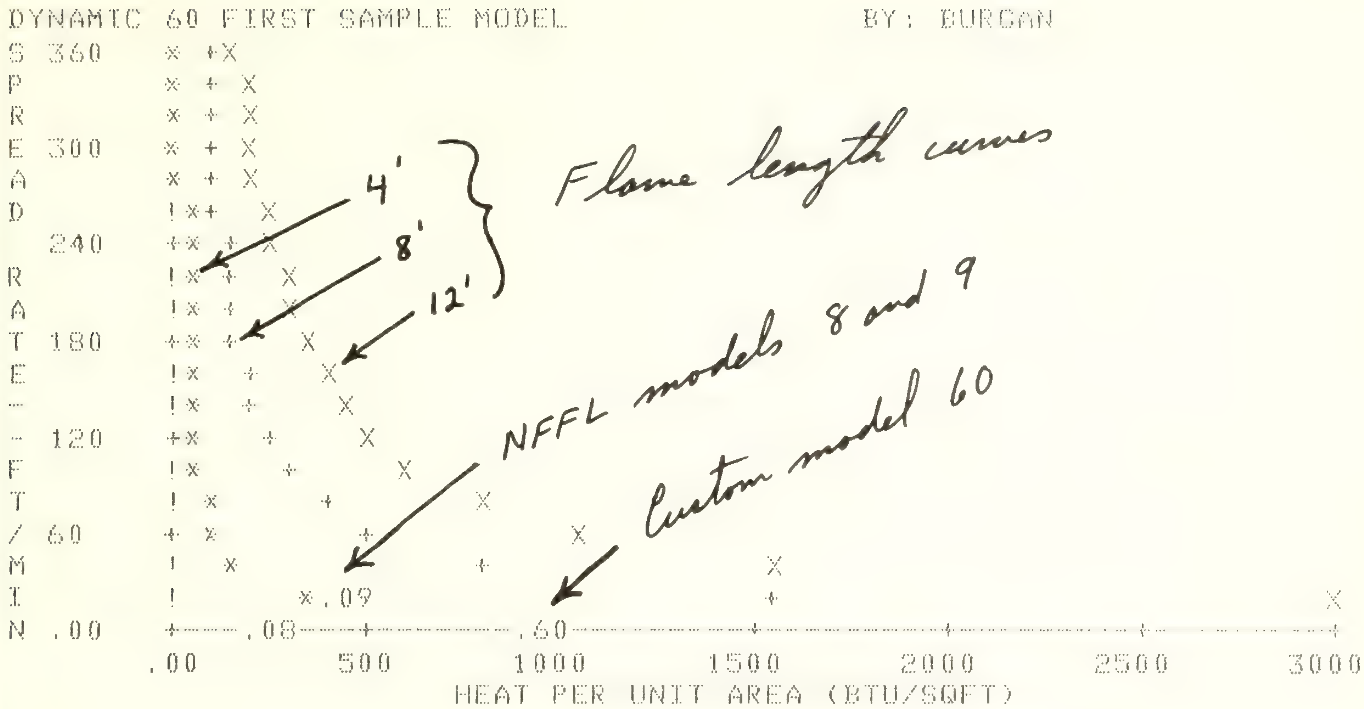


The * define the curve for the 4 percent 1 HR, but it is not labeled because the 8 percent label fell on top of it.



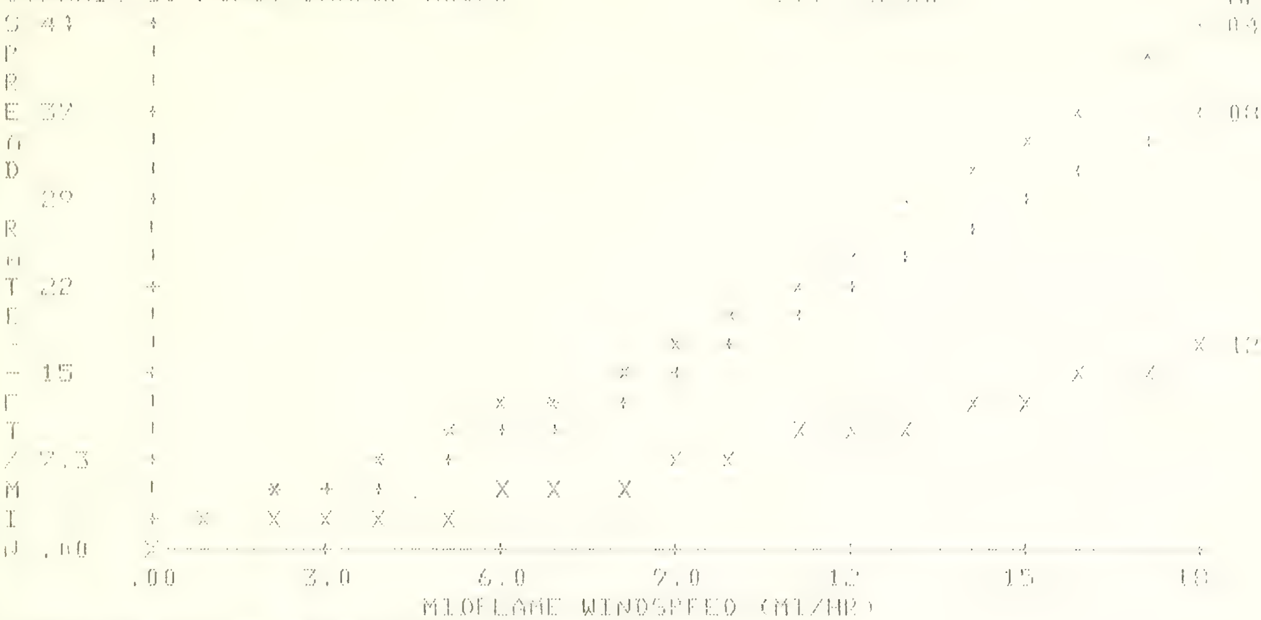
Normal version graphics, standard scaling

With standard scaling, the Y-axis is always scaled as above for spread rate and flame length. This permits overlaying graphs of different fuel models.

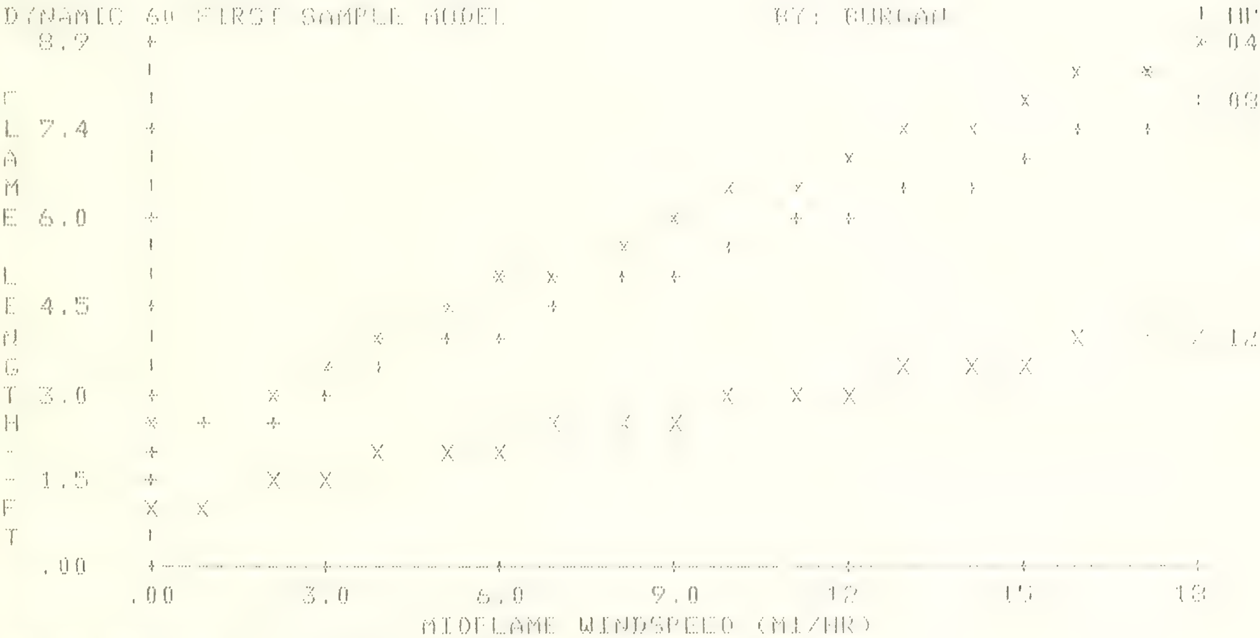

DYNAMIC 60 FIRST SAMPLE MODEL
BY: BURGAN
SPREAD RATE -- FT/MIN
360
300
240
180
120
60
.00
.08
.09
.60
.00
500
1000
1500
2000
2500
3000
HEAT PER UNIT AREA (BTU/SQFT)
Flame length curves
4'
8'
12'
NFFL models 8 and 9
Custom model 60

```
NORMAL VERSION GRAPHICS SECTION.

 DO YOU WANT GRAPH 1 - RATE OF SPREAD? (Y OR N).
>Y

 DO YOU WANT GRAPH 2 - FLAME LENGTH? (Y OR N).
>Y

 DO YOU WANT TO USE:
    1) STANDARD
    2) CALCULATED
 SCALING OF THE Y-AXIS?

 ENTER 1 OR 2
>2

 YOUR 1 HR FM IS    4.
 DO YOU WANT TO PLOT CURVES FOR 2 MORE 1 HR MOISTURES?  (Y OR N).
>Y

 FIRST VALUE?
 RANGE = 2. TO 50.
>8

 SECOND VALUE?
 RANGE = 2. TO 50.
>12

 DO YOU WANT GRAPH 3 - FIRE CHARACTERISTICS CHART?  (Y OR N).
>N
```

Normal version graphics, calculated scaling



PRESS RETURN TO CONTINUE
>



PRESS RETURN TO CONTINUE
>
RUN MORE GRAPHS? (Y OR N)
>N

Normal version graphics, calculated scaling

Calculated scaling uses the full Y-axis range

```
CONTROL SECTION, KEYWORD?
>TECH

TECHNICAL VERSION SET.
CONTROL SECTION, KEYWORD?
>GRAPH
GRAPHIC OUTPUT SET.

TECHNICAL VERSION GRAPHICS SECTION.

DO YOU WANT KEYWORDS FOR X AXIS?  (Y OR N)
>Y

THE KEYWORDS FOR THE X AXIS AND THEIR MEANING ARE:

   KEYWORD      MEANING
   KEY     PRINT THIS KEYWORD LIST
   SA1     1 HR S/V RATIO
   SAH     HERB S/V RATIO
   SAW     WOODY S/V RATIO
   L1      1 HR FUEL LOAD
   L10     10 HR FUEL LOAD
   L100    100 HR FUEL LOAD
   LH      HERB FUEL LOAD
   LW      WOODY FUEL LOAD
   DEPTH   FUEL BED DEPTH
   EXTM    EXTINCTION MOISTURE
   HEAT    HEAT CONTENT
   M1      1 HR FUEL MOISTURE
   M10     10 HR FUEL MOISTURE
   M100    100 HR FUEL MOISTURE
   MHERB   HERB FUEL MOISTURE
   MWOOD   WOODY FUEL MOISTURE
   WIND    MIDFLAME WINDSPEED
   SLOPE   PERCENT SLOPE
DO YOU WANT KEYWORDS FOR Y AXIS?  (Y OR N)
>Y

THE KEYWORDS FOR THE Y AXIS AND THEIR MEANING ARE:

   KEYWORD      MEANING
   FLINT   FIRELINE INTENSITY
   RATE    RATE OF SPREAD
   REAC    REACTION INTENSITY
   FLAME   FLAME LENGTH
   H/A     HEAT PER UNIT AREA
   RSFL    ROS/FL RATIO
   PACK    PACKING RATIO
```

Any of these items can be placed on the X-axis

Any of these items can be placed on the Y-axis

Technical version graphics

```
 X AXIS KEYWORD?
>L1

 ENTER MINIMUM 1 HR FUEL LOAD IN TONS/ACRE
 RANGE = .001 TO 30.
>1

 ENTER MAXIMUM 1 HR FUEL LOAD
>30

 ENTER Y AXIS KEYWORD.
>RATE

 YOU CAN EITHER:
   1) SET THE Y AXIS RANGE
   2) USE THE CALCULATED Y AXIS RANGE
 CALCULATED Y AXIS RANGE FOR RATE OF SPREAD :  (0. TO   10.)
 ENTER 1 OR 2
>1
 ENTER MAXIMUM Y VALUE
>12
```

Set the maximum value to 12

```
 DYNAMIC 60 FIRST SAMPLE MODEL                  BY: BURGAN               1 HR
 S  12   +
 P       !
 R       !
 E  10   +                     XXXXXXXXXXXXXXXXXXXXXXXXXXX
 A       !                XXXXX                           XXXXXXXXXX
 D       !             XXX                                          X
    8.0  +          XXX
 R       !        XX
 A       !      XX
 T  6.0  +    XX
 E       !  XX
 -       ! XX
 -  4.0  + X
 F       !XX
 T       !
 /  2.0  +
 M       !
 I       !
 N   .00 +---------+---------+---------+---------+---------+---------+
        1.0       5.8        11        15        20        25        30
                         1 HR FUEL LOAD (TONS/ACRE)
 PRESS RETURN TO CONTINUE
>

 DO YOU WANT TO CHANGE THE X AXIS, THE Y AXIS OR QUIT?
 ENTER X, Y, OR QUIT
>Y
```

Technical version graphics

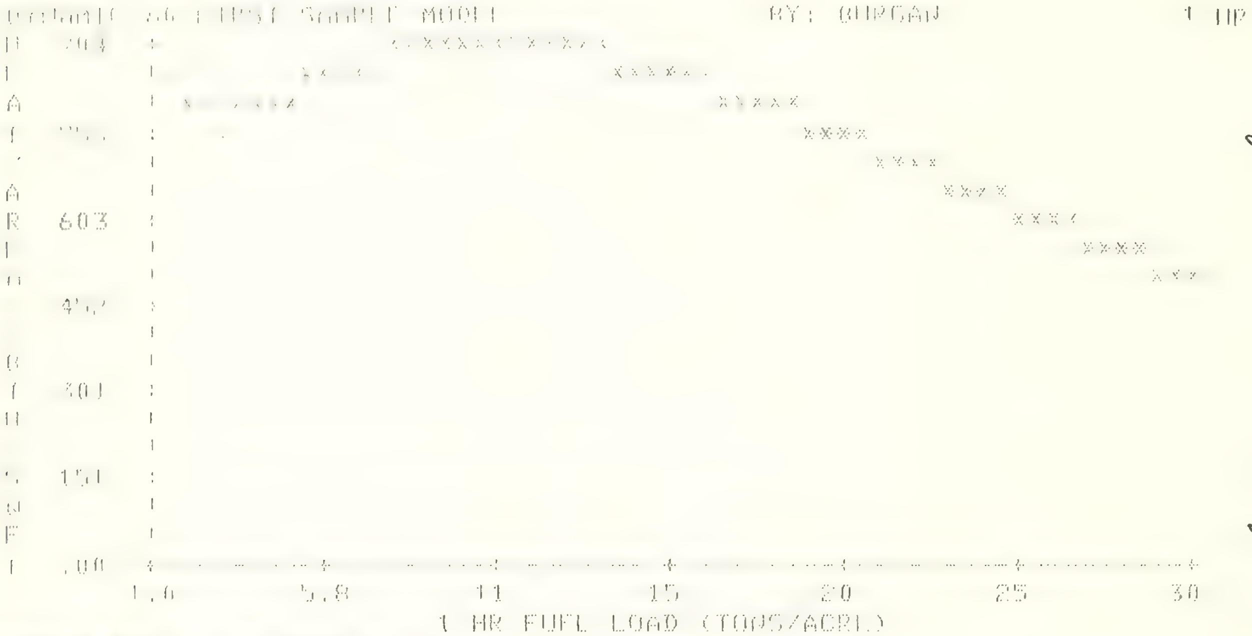
Decided to place a different parameter on the Y-axis

```
ENTER Y AXIS NUMBER
[illegible]
```

Selected heat per unit area

```
YOU CAN EITHER:
  1) SET THE Y-AXIS RANGE
  2) USE THE CALCULATED Y-AXIS RANGE

CALCULATED Y AXIS RANGE FOR HEAT PER UNIT AREA: ( 0 TO [illegible])
ENTER 1 OR 2
2
```

Used the calculated Y-axis range



Technical version graphics

```
PRESS RETURN TO CONTINUE

DO YOU WANT TO CHANGE THE X AXIS, THE Y AXIS OR QUIT?
ENTER X, Y, OR QUIT
X
```

Decided to change the X-axis parameter

```
TECHNICAL VERSION GRAPHICS SECTION.

 DO YOU WANT KEYWORDS FOR X AXIS?  (Y OR N)
>N
 DO YOU WANT KEYWORDS FOR Y AXIS?  (Y OR N)
>N

 X AXIS KEYWORD?
>L10

 ENTER MINIMUM 10 HR FUEL LOAD IN TONS/ACRE
 RANGE = .001 TO 30.
>1

 ENTER MAXIMUM 10 HR FUEL LOAD
>30

 ENTER Y AXIS KEYWORD.
>RATE

 YOU CAN EITHER:
   1) SET THE Y AXIS RANGE
   2) USE THE CALCULATED Y AXIS RANGE
 CALCULATED Y AXIS RANGE FOR RATE OF SPREAD :  (0. TO   16.)
 ENTER 1 OR 2
>2


 DYNAMIC 60 FIRST SAMPLE MODEL                 BY: BURGAN                 1 HR
 S  16    +x
 P        ! xx
 R        !    x
 E  13    +     xx
 A        !        xx
 D        !          xx
    11    +             xx
 R        !               xxx
 A        !                   xxx
 T  7.9   +                       xxx
 E        !                          xxxxx
 -        !                                xxxxx
 -  5.3   +                                     xxxxxx
 F        !                                           xxxxxxxx
 T        !                                                   xxxxxxxxxxx
 /  2.6   +                                                              xxxx
 M        !
 I        !
 N  .00   +-----------+-----------+-----------+-----------+-----------+-----+
         1.0         5.8          11          15          20          25    30
                            10 HR FUEL LOAD (TONS/ACRE)
 PRESS RETURN TO CONTINUE
>

 DO YOU WANT TO CHANGE THE X AXIS, THE Y AXIS OR QUIT?
 ENTER X, Y, OR QUIT
>QUIT
```

Selected 10 hour load

It is a good idea to use a large - even unrealistic - range for your first plot, to see how a parameter can affect the behavior of your model

Technical version graphics

```
 CONTROL SECTION. KEYWORD?
>FILL

 DO YOU WISH TO USE THE CURRENT FUEL MODEL FILE (Y OR N)?
 THE CURRENT FILE IS MYFILE
>Y

 DO YOU WANT TO:
   1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
   2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
   3) CHANGE A FUEL FILE HEADER
   4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
   5) REPLACE A FUEL MODEL IN THE FILE
   6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
   7) GO BACK TO THE CONTROL SECTION

 ENTER 1, 2, 3, 4, 5, 6 OR 7
>1

 ENTER FUEL MODEL NUMBER
 RANGE = 14 TO 99
>61

 MODEL 61 LOADED
 CONTROL SECTION. KEYWORD?
```

After 'getting' a model, you are automatically put back in the 'control' section

Getting a fuel model from the file

```
>FILE
```
Get back to the file section

```
 DO YOU WISH TO USE THE CURRENT FUEL MODEL FILE (Y OR N)?
 THE CURRENT FILE IS MYFILE
>Y

 DO YOU WANT TO:
    1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
    2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
    3) CHANGE A FUEL FILE HEADER
    4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
    5) REPLACE A FUEL MODEL IN THE FILE
    6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
    7) GO BACK TO THE CONTROL SECTION

 ENTER 1, 2, 3, 4, 5, 6 OR 7
>2
          SAMPLE FUEL MODEL FILE
 60 FIRST SAMPLE MODEL
 61 SECOND SAMPLE MODEL
```

← Fuel model file description from the file 'header'

List of models in the file

Listing the models in the file

Changing a fuel file header

DO YOU WANT TO:
1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
3) CHANGE A FUEL FILE HEADER
4) ADD THE FUEL MODEL JUST BUILT TO THE FUEL MODEL FILE
5) REPLACE A FUEL MODEL IN THE FILE
6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7
>3

ENTER PASSWORD
>NFFL

ENTER NEW PASSWORD (4 CHAR MAX)
>FFLN ← {Password changed in this case, but you could enter the same password (NFFL) if you didn't want to change it.

THE CURRENT FUEL FILE DESCRIPTION IS:
SAMPLE FUEL MODEL FILE
DO YOU WANT TO CHANGE IT? (Y OR N)
>Y

ENTER COMMENT TO DESCRIBE THIS FUEL FILE (72 CHAR MAX)

>EXAMPLE FUEL MODEL FILE ← Changed the file description, but you don't have to if you say NO to the above question

FUEL FILE HEADER CHANGED

DO YOU WANT TO:
1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
3) CHANGE A FUEL FILE HEADER
4) ADD THE FUEL MODEL JUST BUILT TO THE FUEL MODEL FILE
5) REPLACE A FUEL MODEL IN THE FILE
6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7
>2
EXAMPLE FUEL MODEL FILE ← New fuel file descriptor
50 FIRST SAMPLE MODEL
51 SECOND SAMPLE MODEL

```
DO YOU WANT TO:
   1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
   2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILI
   3) CHANGE A FUEL FILE HEADER
   4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
   5) REPLACE A FUEL MODEL IN THE FILE
   6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
   7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7
>4

 A FUEL MODEL WITH THIS NUMBER ALREADY EXISTS IN THE FILE
RETURNING TO THE CONTROL SECTION SO YOU CAN RENUMBER THE MODEL
CONTROL SECTION, KEYWORD?
>RENUMBER
```

← Must change fuel model number

```
ENTER THE NUMBER YOU WANT ASSIGNED TO THIS CUSTOM MODEL
RANGE = 14 TO 99
>62
```

← New number

```
ENTER FUEL MODEL NAME (32 CHARACTERS MAXIMUM).
--------------------------------
>SECOND COPY OF MODEL 61
```

Called it this because it really is the same model

```
IS YOUR PROPOSED FUEL MODEL DYNAMIC(1) OR STATIC(2)?

DYNAMIC MODELS ADJUST FOR SEASONAL DRYING THROUGH TRANSFER
OF LIVE HERBACEOUS LOAD BETWEEN LIVE HERBACEOUS AND 1 HOUR
TIMELAG CLASSES, AS A FUNCTION OF HERBACEOUS FUEL MOISTURE.

STATIC MODELS HAVE CONSTANT LOADS IN ALL LIVE AND DEAD
FUEL CLASSES.
ENTER 1 OR 2
>2
```

Renumbering a model provides a chance to change its status as static or dynamic

```
PROGRAM CONTROL IS THROUGH THE USE OF KEYWORDS.
DO YOU WANT A LIST OF KEYWORDS AND THEIR FUNCTIONS? (Y OR N)
>N

WHENEVER 'KEYWORD?' IS PRINTED, TYPE THE KEYWORD FOR
THE NEXT TASK YOU WANT TO ACCOMPLISH.  YOUR FIRST RESPONSE
SHOULD BE THE KEYWORD 'NORM' OR 'TECH' TO GET THE VERSION
YOU WANT.
```

↖ Just a reminder. You don't have to do this unless you want the other version.

Adding a model to the file

```
CONTROL SECTION, KEYWORD?
>FUEL

DO YOU WISH TO USE THE CURRENT FUEL MODEL FILE (Y OR N)?
THE CURRENT FILE IS MYFILE
>Y

DO YOU WANT TO:
   1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
   2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
   3) CHANGE A FUEL FILE HEADER
   4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
   5) REPLACE A FUEL MODEL IN THE FILE
   6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
   7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7
>4

ENTER PASSWORD
>LTEN

FUEL MODEL 62 WRITTEN TO FUEL MODEL FILE

DO YOU WANT TO:
   1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
   2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
   3) CHANGE A FUEL FILE HEADER
   4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
   5) REPLACE A FUEL MODEL IN THE FILE
   6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
   7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7
>7
```

This time the model was added OK

Adding a model to the file

```
CONTROL SECTION. KEYWORD?
>FUEL

 FUELS MANIPULATION SECTION.
   TO USE ONE OF THE 13 NFFL FUEL MODELS TYPE 'NFFL'.
   TO INPUT ALL FUELS DATA TYPE 'NEW'.
   TO CHANGE EXISTING FUELS DATA TYPE 'CHANGE'.
   TO LIST CURRENT FUELS DATA TYPE 'LIST'.
   TO GET OUT OF THE FUELS SECTION TYPE 'QUIT'.

 KEYWORD?
>CHANGE

 FUEL MODIFICATION SECTION.
 ENTER KEYWORD 'QUIT' AFTER LAST CHANGE.

 DO YOU WANT A LIST OF FUEL MODEL KEYWORDS?  (Y OR N)
>N

 KEYWORD?
>EXTM

 MOISTURE OF EXTINCTION?
 RANGE = 10. TO 60.
>30

 KEYWORD?
>QUIT

 FUELS MANIPULATION SECTION.
 TYPE 'NFFL', 'NEW', 'CHANGE', 'LIST', OR 'QUIT'

 KEYWORD?
>LIST

               CURRENT VALUES OF FUEL MODEL PARAMETERS
 STATIC 62. SECOND COPY OF MODEL 61             BY: BURGAN

        LOAD (T/AC)          S/V RATIOS              OTHER
     ------------------   ------------------   ---------------------
     1 HR          1.62   1 HR         1728.   DEPTH             0.67
     10 HR         4.00   LIVE HERB       0.   HEAT CONTENT   8000.
     100 HR        7.20   LIVE WOODY      0.   EXT MOISTURE     30.
     LIVE HERB     0.00
     LIVE WOODY    0.00

 FUELS MANIPULATION SECTION.
 TYPE 'NFFL', 'NEW', 'CHANGE', 'LIST', OR 'QUIT'

 KEYWORD?
>QUIT
```

Decided to change model 62 slightly before replacing it in the file

Replacing a model in the file

```
CONTROL SECTION, KEYWORD?
>FILE

DO YOU WISH TO USE THE CURRENT FUEL MODEL FILE (Y OR N)?
THE CURRENT FILE IS MYFILE
>Y

DO YOU WANT TO:
   1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
   2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
   3) CHANGE A FUEL FILE HEADER
   4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
   5) REPLACE A FUEL MODEL IN THE FILE
   6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
   7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7
>5

ENTER PASSWORD
>LFFN

FUEL MODEL 62 WRITTEN TO FUEL MODEL FILE
```

Model 62 was found in the file and replaced.

Replacing a model in the file

```
DO YOU WANT TO:
   1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
   2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
   3) CHANGE A FUEL FILE HEADER
   4) ADD THE FUEL MODEL JUST BUILT, TO THE FUEL MODEL FILE
   5) REPLACE A FUEL MODEL IN THE FILE
   6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
   7) GO BACK TO THE CONTROL SECTION

ENTER 1, 2, 3, 4, 5, 6 OR 7
>6

HOW MANY MODELS DO YOU WANT TO DELETE?
RANGE = 0 TO 5
>1

ENTER NUMBER OF FIRST MODEL TO BE DELETED
>62


FUEL MODEL 62 DELETED
```

Deleting a model from the file

```
 DO YOU WANT TO:
    1) GET A PREVIOUSLY BUILT SITE SPECIFIC FUEL MODEL
    2) LIST THE NUMBERS AND NAMES OF FUEL MODELS IN YOUR FILE
    3) CHANGE A FUEL FILE HEADER
    4) ADD THE FUEL MODEL JUST BUILT TO THE FUEL MODEL FILE
    5) REPLACE A FUEL MODEL IN THE FILE
    6) DELETE A FUEL MODEL FROM THE FUEL MODEL FILE
    7) GO BACK TO THE CONTROL SECTION

 ENTER 1, 2, 3, 4, 5, 6 OR 7
>1

 ENTER FUEL MODEL NUMBER
 RANGE = 14 TO 99
>60

 MODEL 60 LOADED
 CONTROL SECTION. KEYWORD?
>TI59

** TI-59 DATA FOR DYNAMIC MODEL 60. FIRST SAMPLE MODEL
  MODEL PARAMETER    PARAMETER VALUE    TI REG NO
   ---- LOADS ----
   1 HR                    0.4729          11
   10 HR                   0.3760          12
   100 HR                  0.3177          13
   LIVE HERB               0.0675          15
   LIVE WOODY              0.0275          16

   -- S/V RATIO --
   1 HR                 1923.              17
   10 HR                 109.              18
   100 HR                 30.              19
   LIVE HERB            1500.              21
   LIVE WOODY            800.              22

   ---- OTHERS ----
   HEAT CONTENT         8440.              23
   ROS FOR IC         999999.              24
   EXT MOISTURE           13.              25
   DEPTH                   0.81            26
   M WS CONSTANT           1.              27
PRESS RETURN TO CONTINUE
>

THE WIND ADJUSTMENT FACTOR TO REDUCE 20 FOOT WINDSPEED
TO MIDFLAME WINDSPEED FOR FULLY EXPOSED FUELS IS 0.4
CONSULT ROTHERMEL'S HOW TO PREDICT ..... BOOK
FOR PARTIALLY OR FULLY SHELTERED FUELS.
CONTROL SECTION. KEYWORD?
>QUIT

DO YOU REALLY WANT TO TERMINATE THIS RUN? (Y OR N).
>Y

TSTMDL RUN TERMINATED.
******************************
```

Obtaining TI-59 fuel model card data

APPENDIX D: FUEL MODEL FILE STRUCTURE

The fuel model file serves as the basic means of communication between the programs of the BEHAVE system. The structure of the file is:

1. A "header" record containing the user's password and a general description of the models in the file.
2. One record for each fuel model in the file.
3. An end of file mark.

If fuel models have been deleted from a file, you may find some extraneous records after the first end of file mark. They should not be a cause for concern. With some computers you may see these records if you look at the file with the editor. Other computers may delete them.

The records of the file are described in detail below.

"Header" Record

Column(s)	Data recorded
1 - 4	User's password
5 - 6	Blank
7 - 78	File description
79	Blank
80	A letter of the alphabet

The letter in column 80 will be used to check whether or not the fuel model has the current format. When BEHAVE is implemented this letter will be A. If the format changes in the future, the letter will be changed to B, then C, etc.

Fuel Model Card Records

Column(s)	Data recorded
1 - 2	Fuel model number
3	Wind reduction factor
4 - 35	Fuel model name
36 - 39	1-h load
40 - 43	10-h load
44 - 47	100-h load
48 - 51	Live herbaceous load
52 - 55	Live woody load
56 - 59	Fuel bed depth
60 - 64	Heat content
65 - 66	Extinction moisture
67 - 70	1-h S/V ratio
71 - 74	Live herbaceous S/V ratio
75 - 78	Live woody S/V ratio
79	Letter
80	Dynamic (1), static (0) code

The formats used to write and read these records are:

"Header" record:

```
Write format (A4,2X,18A4, 1X, A1))
Read format (A4,2X,18A4, 1X, A1))
```

Fuel model records:

```
Write format (I2,I1,32A1,6I4,I5,I2,3I4,A1,I1)
Read format (F2.0,I1,32A1,6F4.2,F5.0,F2.0,3F4.0,A1,I1)
```

APPENDIX E: WEIGHTING PROCEDURES USED IN PROGRAM NEWMDL

Field data are usually collected for more than one of the fuel components--litter, grass, shrubs, or slash. The data collected for each component will differ. For example, the 1-h S/V ratio for litter will not likely be the same as for shrubs or grass. And the heat content may be different for slash than for the live leaves and twigs of shrubs. Therefore, while the NEWMDL program will accept the diversity of data collected on the various fuel components, it must eventually be condensed to "average" values that represent the entire fuel complex. This appendix describes the weighting procedures used to calculate average heat content, 1-h S/V ratio, dead fuel extinction moisture, and fuel bed depth for the "first cut" fuel model produced by the NEWMDL program.

Heat Content

1. Calculate the mean total surface area of fuel in the j^{th} class of the

dead category: $$A_{1j} = \frac{(\sigma)_{1j}(W_o)_{1j}}{(\rho_p)_{1j}}$$

and the

live category: $$A_{2j} = \frac{(\sigma)_{2j}(W_o)_{2j}}{(\rho_p)_{2j}}$$

where

σ = surface-area-to-volume ratio of the j^{th} class of the dead fuel category

W_o = ovendry load in the j^{th} class of the dead fuel category

ρ_p = particle density (32 lb/ft^3)

2. Calculate the mean total surface area of the

dead category: $$\bar{A}_{1j} = \sum_{j=1}^{3} A_{1j}$$

and the

live category: $$\bar{A}_{2j} = \sum_{j=1}^{2} A_{2j}$$

and the mean total surface area of the complex

$$\bar{A}_T = \sum_{i=1}^{2} \bar{A}_i$$

3. Determine the fraction of the total surface area in the

dead category: $$f_1 = \frac{\bar{A}_1}{A_T}$$

live herbaceous class: $$f_{2,1} = \frac{\bar{A}_{2,1}}{\bar{A}_2}$$

$$\text{live woody class: } f_{2,2} = \frac{\bar{A}_{2,2}}{\bar{A}_2}$$

4. Calculate the weighted heat content for all fuel classes and categories

$$H_w = f_1 H_{1,1} + f_{2,1} H_{2,1} + f_{2,2} H_{2,2}$$

where

$H_{1,1}$ = dead fuel heat content (Btu/lb)

$H_{2,1}$ = live herbaceous heat content (Btu/lb)

$H_{2,2}$ = live woody heat content (Btu/lb)

One-Hour Timelag Surface-to-Volume Ratio

1. Calculate weighting factors for each component

$$f_i = W_i \sigma_i / 32$$

where

W_i = ovendry load of each component

σ_i = 1-h S/V ratio of each component

2. Calculate the "characteristic" 1-hour S/V ratio for the fuel complex

$$\tilde{\sigma}_{1,1} = \sum_{i=1}^{4} f_i \sigma_i / \sum_{i=1}^{4} f_i$$

Dead Fuel Extinction Moisture and Fuel Bed Depth

1. Convert total load of each component from tons per acre to pounds per square foot

2. Calculate the packing ratio for litter, grass, and slash components as

$$\beta_{cp} = \frac{W_{cp}}{32\delta_{cp}}$$

where

β_{cp} = component packing ratio

w_{cp} = component load (lb/ft^2)

δ_{cp} = component depth

3. Calculate the extinction moisture (%) for litter, grass, and slash components

$$M_{xcp} = 100(0.12+4.8\beta_{cp})$$

where

M_{xcp} = component extinction moisture

Component extinction moisture (M_{xcp}) estimates are based on the relationship of extinction moisture to packing ratio for the 13 NFFL fuel models (fig. 26). These models can be separated into two groups:

- shrubs and tall coarse grass (models 3-7)
- shorter, finer grasses (models 1 and 2) and fuels that are primarily horizontal (models 8-13)

The two groups were considered separately. The extinction moisture of the first group is set, in subroutine SHRUB, as 0.35 if the leaves are said to contain oils and waxes, 0.20 if not.

The extinction moisture of the second group is calculated using the regression line fitted to the points plotted for models 1-2, and 8-13.

4. Calculate extinction moisture for the fuel model

$$M_x = \sum_{i=1}^{4} M_{xcp} W_{cp} / W_o$$

where

w_o = total ovendry load

5. Depth for the fuel complex is similarly calculated

$$\delta = \sum_{i=1}^{4} \delta_{cp} W_{cp} / W_o$$

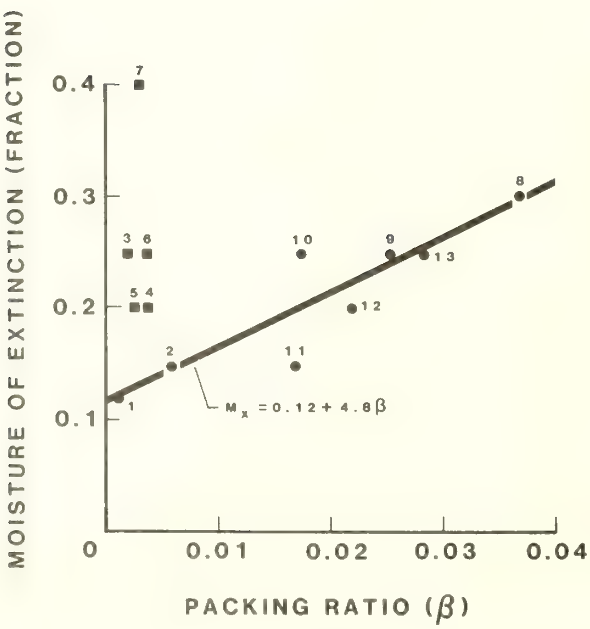


Figure 26.--Moisture of extinction is assigned for shrub-type fuels (models 3-7), but calculated from the extinction moisture equation for other fuel types (models 1-2 and 8-13).

☆ U. S. GOVERNMENT PRINTING OFFICE: 1984—776-032/1067 REGION NO. 8

Burgan, Robert E.; Rothermel, Richard C. BEHAVE: fire behavior prediction and fuel modeling system--FUEL subsystem. General Technical Report INT-167. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 126 p.

This manual documents the fuel modeling procedures of BEHAVE--a state-of-the-art wildland fire behavior prediction system. Described are procedures for collecting fuel data, using the data with the program, and testing and adjusting the fuel model.

KEYWORDS: fire, fuels, fire behavior prediction

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, UT 84401**

General Technical
Report INT-168

May 1984

The Challenge of Producing Native Plants for the Intermountain Area

Proceedings: Intermountain Nurseryman's Association 1983 Conference August 8-11, 1983 Las Vegas, Nevada

FOREWORD

Native plant materials are gaining status in the nursery industry. There is a current imbalance of supply and demand for the natives. Plant scientists and a growing number of nurseries are working to make more native plants economically available.

This conference was designed to provide an overview of procedures involved in the propagation of native plant materials common to the Intermountain area. This proceedings includes the major papers delivered at the meeting.

-- Patrick M. Murphy

COVER PHOTO: The Leviathan Mine, an open-pit sulfur mine, illustrates the challenges facing resource managers and researchers in revegetating severely disturbed areas in the Intermountain area. The Leviathan is a major source of pollution to the Lahontan watershed on the east side of the Sierra Nevada. Recently, $3 million was appropriated through the California Regional Water Quality organization to reclaim the site.

The Challenge of Producing Native Plants for the Intermountain Area

Proceedings: Intermountain Nurseryman's Association 1983 Conference August 8-11, 1983 Las Vegas, Nevada

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CONTENTS

GERMINATION OF SEEDS OF WILDLAND PLANTS

James A. Young, Jerry D. Budy and Raymond A. Evans

ABSTRACT: Germination of wildland seeds is often dependent on proper seed collection and storage. Timing, seed collection, and the moisture content of seeds in storage often influences germination. A systematic approach to germination testing often will pinpoint the type of dormancy of seeds in wildland species and lead to germination enhancement.

INTRODUCTION

Successful germination of seeds of plants collected from wildlands starts with proper collection of the seeds. Both the timing of collection and the handling of the freshly harvested seeds are important.

TIMING THE COLLECTION OF WILDLAND SEEDS

Many wildland plant species have indeterminate type inflorescences where flowering and maturity are continuous for extended periods. This means that seeds are ripe and falling from the inflorescences at the same time blooming is still occurring at other locations on the inflorescence. It is difficult to avoid collecting immature seeds in this situation. For determinate species that mature at one time there is the danger of the seeds suddenly being dehisced and lost unless they are collected slightly before maturity.

Slightly immature seeds are not necessarily poor germinators. The propagator has to determine the influence of maturity on germination through trials. To conduct meaningful trials, it is necessary to label the seed collection with some detail of the phenological stage of development, where the seed lot was collected, and to maintain the identity of the seed lot through germination trials.

Various maturity classes of seeds can be collected by separating collections made on the same plant, moving from early maturing south to north slope communities, or by collecting at higher elevation within the range of the species.

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HANDLING FRESHLY HARVESTED SEEDS

A seed is a living organism in a resting stage, but it is most important to remember that it is alive! Freshly harvested seeds have too high a moisture content for safe storage. The moisture content of the seed must be allowed to reach equilibrium with the atmosphere. In the Intermountain area this is usually simple because the relative humidity of our air during the summer and fall is usually quite low.

For freshly harvested seeds to reach a moisture equilibrium they must be stored in such a manner to allow for free aeration. Uncoated paper or mesh bags make good storage containers for initial drying. Never use plastic bags for storage of freshly harvested seeds!

Artificial drying, especially at high temperatures, is usually not necessary, and often not desirable. Screen freshly harvested material to remove high moisture content trash. This will reduce drying time.

Fleshy fruits require prompt treatment to remove the fleshy material to avoid spoilage or mummification of the fruits.

The seeds of species collected from marsh or wetland environments often require special handling. The technique used depends on the species involved, but often it is necessary to keep the seeds in a cool, wet environment or actually stored in water to avoid acquiring dormancy or loss of viability.

SEED CLEANING

Generally the sooner the seeds are cleaned and placed in storage after they reach moisture equilibrium, the less chance of predation from birds or small mammals or contamination from insects.

Avoid rough handling of seeds during cleaning. Remember the seed is alive and the embryo can be very fragile. Never use a hammer mill in seed processing unless you have first determined by careful testing that seed viability is not being adversely affected by the process.

Proper seed cleaning makes subsequent handling of the seeds in the germination process much simpler. Especially if the seed lot contains trash or empty or obviously immature seeds, much time may be wasted sorting the material to find germinable seeds.

SEED STORAGE

To avoid problems with storage insects, start with clean, insect-free storage conditions. Do not introduce pests with the seeds to be stored. Cool storage conditions lessen the chances of insect problems.

The key to seed storage is maintaining proper moisture conditions so that the seeds remain alive, but ungerminated. Remember that the amount of water that the storage atmosphere will hold as a vapor is directly related to temperature. If you decrease the storage temperature of a sealed container, moisture condensation will occur.

Storage in paper or mesh bags in a cool, dry location is satisfactory for most seeds. Once the seeds have reached moisture equilibrium, storage in glass jars or plastic boxes is possible to avoid insect or mold contamination. Some seeds can be stored easily in small lots, but suffer losses in viability when quantities of seeds are stored together. Some seeds have inherently very short storage lives and seed stocks of these species must be removed annually.

GERMINATION TESTING

Two common determinations are made from seed tests: viability and germinability. Viability simply means the seed is alive. It does not indicate if the seed will germinate. Viability tests may be as simple as cutting a seed or fruit with a knife blade to determine if an embryo is present. More complex viability tests involve the use of the chemical, tetrazolium. This chemical, after proper sectioning and preparation of the seed, has the property to accept hydrogen atoms from dehydrogentate enzymes during the respiration process in viable seeds. Essentially, respiring or living tissue in the seeds is evidenced by a red color change.

The fact that the seeds or fruits contain living tissue does not mean the embryo will germinate. This is a common misinterpretation. For seeds of the major crop species, standards have been developed that relate the tetrazolium reaction to potential germination. These standards have not been developed for the seeds of most wildland species.

Germinability is a much more meaningful statistic for individuals interested in propagating plants from seeds. To obtain an estimate of germinability, the seeds must be subjected to a germination test. The Association of Official Analysis (AOSA) prescribes the rules for testing seeds of specific species. For example, seeds of Canada bluegrass (Poa compressa) are tested on germination paper, at 15/25 or 15/30°C (15°C for 8 hours/30°C for 16 hours daily), with light during the 8-hour period and potassium nitrate (KNO_3) added to the substrate. Unfortunately, for the seeds of most wildland species, no standard germination tests exist. The AOSA has draft standards for about 100 wildland species. Until the standards are accepted and/or developed for the seeds of important wildland species, germination figures as given on seed tags are meaningless.

DETERMINING GERMINABILITY OF WILDLAND SPECIES

Afterripening

The seeds of many species will not germinate soon after they are harvested. As time passes, germinability of these seeds gradually increases until they may be highly germinable.

This time period that must pass before the seeds will germinate has been termed the afterripening requirement. These requirements are not responsive to external stimuli. One cannot do anything about them but wait.

This type of dormancy has been attributed to immature embryos that require post-harvest time to mature.

A variant of this type of dormancy is called temperature-dependent afterripening. In this case, seeds will not germinate at one incubation temperature (usually moderate to high incubation temperatures), but will germinate at other temperatures (usually cold incubation temperatures).

Practically, this means the nurseryman has to wait to obtain germination with the seeds of certain species. Do not confuse afterripening with stratification requirements where the dormancy does respond to external stimuli. Stratification requirements will be discussed later.

Hard Seed Coats

If seeds do not initially germinate or fail to germinate after a reasonable afterripening period, the first germination factor to check is to see if the seeds imbibe water. This can be done by pressing the seed with a thumbnail or by cutting. If the interior of the seed appears chalky and hard, water has not been imbibed through the seed coat. Imbibed seeds should be soft and easily squashed with the thumb.

Seeds with coats that do not freely allow the passage of water are termed hard seeds.

Scarification

To break the hard seed coats some form of scarification is required. This scarification can be accomplished with mechancial, thermal, or chemical treatments. If the seeds are large enough, scarification may be accomplished by filing a notch in the coat or clipping so as not to injure the embryo. Smaller seeds can be scarified by mechanically abrading them in some manner. This may be as simple as rubbing the seeds between sheets of sandpaper.

Mechanical scarifiers have been developed with abrasive lined drums in which the seeds are rotated. Virtually any mechanical scarification that results in increased germinability results in decreased viability. In other words, you pay the price for getting some seeds to germinate by fatally injuring other seeds. Hammer mills are used for scarifying seeds. Great care must be taken to not excessively injure seeds with these treatments. Minimum clearance between concave bars in threshing machines can be used to crack the seeds of legumes to obtain increased germinability, but again, with some reduction in viability.

Thermal scarification is obtained by dropping seeds into boiling water and then allowing the water to cool. Such treatment may have many other influences such as thermal shock to the embryo or leaching soluble inhibitors. Thermal cracking of seed coats is facilitated by fall seeding at shallow depths with exposure to freezing temperatures.

Concentrated sulfuric acid is used to remove hard seed coats. This treatment is difficult to control and may have many side effects. The duration of treatment has to be determined for individual seed lots. Heating from the acid reaction with rinse water and hydrolysis of the seed tissue may induce germination other than through the intended increased imbibition of water.

Always try to control the temperature of the acid-treated seeds in a water bath, rinse a small amount of acid and seeds in a large volume of water, and use a neutralizing solution after the treatment.

Stratification

Seeds that imbibe water but fail to germinate are good candidates for stratification. Do not confuse this word with scarification. Stratification involves placing seeds in a wet environment at temperatures that are not conducive to germination. For most western plants these are temperatures too cold for germination. Such treatments are termed cool-moist stratification. The duration of stratification requirements can range from a few days to many months. For prolonged stratification a substrate must be furnished for moisture retention. Historically peat has been used. Commonly used materials include sand and vermiculite.

Naked stratification has proven effective for the seeds of some species of conifers. This is accomplished by soaking the seeds overnight in water and then placing the damp seeds in plastic bags that are sealed for the duration of the stratification.

Special stratification conditions include prolonged soaking in refrigerated baths that are saturated with oxygen or by using activated charcoal as a stratification substrate.

Some species require specific stratification temperatures. Their seeds are very difficult to germinate without prolonged experimentation.

Nurserymen have long solved stratification problems by fall planting seeds and allowing nature to supply the treatment. In cold areas where snow cover is prolonged, such practices can be quite effective. The interface between continuous snow cover and the surface of the seedbed usually is near 0°C, a near-ideal stratification environment. Any interruption of temperature or moisture conditions during the stratification period results in prolonging the stratification requirement. Covering seeds in flats and covering them with sand and placing the flats outdoors on the northside of a greenhouse can provide a test environment for the stratification of seeds whose requirements are not known.

The seeds of several eastern hardwoods require periods of warm-moist stratification for germination. Some species require warm-moist stratification followed by cold-moist stratification.

Nitrate Ion

The most influential factor in enhancing germination of seeds is often enrichment of the germination substrate with nitrate ions. The nitrate is usually supplied as potassium nitrate (KNO_3) at concentrations ranging from 10^{-1} to 10^{-3} mmoles (1.0 to 0.01 g per litter of water). In the field or nursery bed, flushes of spring germination may be associated with nitrification and the availability of nitrate nitrogen in the seedbed.

Gibberellic Acid

The mode of action of gibberellic acid in seed germination is not known, but very low concentrations of this growth regulator can greatly enhance germination. Concentrations of from 1 to 250 parts per million (p/m) are commonly used in germination enhancement. Combinations of gibberellic acid and potassium nitrate are often more effective than either material alone. Both of these materials can be obtained from chemical supply houses. The potassium nitrate is more easily obtained than gibberellin.

A good balance is needed for preparing the minute concentrations of gibberellic acid. A solution with a concentration of 1 p/m of gibberellic acid consists of 0.001 grams of gibberellic acid dissolved in 1,000 milliliters of water. Gibberellic acid is sold as a 10-percent active ingredient preparation, which makes the weighing simpler. One alternative is to prepare higher concentrations than needed and dilute to the desired concentration. For example, 1,000 p/m would be 1 g in 1,000 ml; however, gibberellic acid is relatively expensive and breaks down very rapidly under warm temperatures

Hydrogen Peroxide

Seeds of several species, especially members of the rose family, have their germination enhanced by soaking in hydrogen peroxide solutions. Dramatic germination enhancement has been obtained with seeds of bitterbrush (Purshia tridentata) and curlleaf mountain mahogany (Cercocarpus ledifolius).

A wide range of concentrations from 1 to 30 percent is effective. Generally, the higher the concentration, the shorter the soaking time, but the greater the risk of damaging the seed. Hydrogen peroxide is a very reactive chemical. Concentrations greater than 3 percent are particularly dangerous to handle.

Other Chemicals

A large number of other chemicals have been used to enhance germination. These include, among others, ethylene producing compounds and various sulphydryl compounds.

Light

Many seeds are sensitive to light during germination. This light or phytochrome reaction involves germination stimulation by near red light and dormancy inductions by far red light. Generally cool-white florescent light enhances germination and incandescent light should be avoided.

Practically, seeds that require light for germination have to placed virtually on the surface of the seedbed. The seeds should be pressed into the seedbed for optimum moisture transfer.

SEEDBED REQUIREMENTS

Seeds have to take moisture up from the germination substrate faster than they lose it to the atmosphere. In a well-firmed seedbed, optimum germination conditions can occur with proper water management. Planting small seeds on the surface of a firmed seedbed and covering them with vermiculite can produce a quality germination environment.

Generally only seeds with external mucilage can germinate on the surface of seedbeds. Exceptions are seeds such as Russian thistle (*Salsola iberica*) with extremely rapid germination.

Even seeds with extremely low percentage germination can give satisfactory establishment if sufficient seeds are planted in a quality seedbed.

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PRODUCING BAREROOT SEEDLINGS OF NATIVE SHRUBS

Nancy Shaw

ABSTRACT: Bareroot planting stock of native shrub species is being requested for soil stabilization, range and wildlife habitat improvement, and low-maintenance landscaping projects in the Intermountain region. Shrub seedlings of a number of species are successfully grown using modifications of techniques developed for the propagation of conifers and introduced shrubs. Refinement of techniques and solutions to specific cultural problems in the production of individual species should improve the quality of stock being produced.

INTRODUCTION

Bareroot seedlings of introduced hardwood tree and shrub species traditionally used in windbreak and conservation plantings are routinely produced by many Federal, State, and private nurseries. In the Intermountain region the need, and in some cases the legal requirement (McArthur 1981), for native species to revegetate disturbed lands has led to the production of a number of native shrubs as bareroot stock. Seed and transplant stock of species suited to specific habitat types are needed for reclamation of disturbed sites, range and wildlife habitat improvement, and low maintenance landscaping.

The decision to use bareroot or container planting stock depends upon a number of factors:

1. Species required. Although some species are difficult to grow as bareroot stock, others have been successfully propagated (tables 1, 2) using modifications of cultural practices developed for conifers. Information relating to the germination and growth of related species (for example, *Rosa*, *Rhus*, or *Prunus* spp.) has also been applied. Cultural practices are being refined based on experience gained in growing native plants at specific nursery sites. Consequently, techniques and information exist that are not presently available in the literature.

2. Characteristics of the planting site. Both container and bareroot seedlings have been successfully planted on a wide variety of wildland sites, although bareroot stock generally does not perform as well on adverse sites (Hodder 1970), particularly rocky areas where there is inadequate soil to pack around the root system.

3. Scheduling. The time from seed collection to lifting of bareroot stock varies from approximately 11 months for fall lifting 1-0 big sagebrush (*Artemisia tridentata*) to nearly 3 years for species such as Rocky Mountain maple (*Acer glabrum*) that are lifted as 2-0 stock. For some species sowing and lifting may be scheduled for either fall or spring.

4. Cost. Bareroot seedlings generally cost less than seedlings grown in containers. Consequently, their use may often be justified economically. Handling and transportation of bareroot seedlings must be carefully planned to protect plants from desiccation and overheating before planting (Dahlgreen 1976). However, bareroot seedlings are much less bulky than container seedlings, and if adequate storage facilities are available, they can be transported and maintained with much less difficulty and at a lower cost (Stevens 1981).

PLANNING AND SCHEDULING

For both speculation and contract growing the source of seed or cuttings should be carefully selected. Extensive morphological and physiological variation exists among populations of individual native shrub species (Stutz 1974; Blauer and others 1975; Welch and Monsen 1981). Populations vary in their range of adaptation, growth habit, growth rates, palatability, nutrient value, soil stabilizing capability, and ease of propagation. The opportunity exists to select and market transplants using seed or cuttings from populations adapted to the planting site that exhibit characteristics compatible with specific planting goals.

Seed production of many shrub species is erratic and scheduling problems may make seed collection difficult. Seed of some minor species is not harvested regularly by commercial collectors. Seed banks may be maintained to avoid these problems. Bareroot stock of easily rooted species may be

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propagated from cuttings if seed is unavailable or difficult to germinate.

All steps in the propagation of each species must be carefully scheduled. Seed and cuttings must be collected during the appropriate season (see Plummer and others 1968; U.S. Department of Agriculture, Forest Service 1974; Hartmann and Kester 1975; Vories 1981). Adequate time must be allotted for seed processing, testing, presowing treatments, field or laboratory stratification, and field production. Most seedlings are lifted after one year's growth in the seedbed, although a few species may require two growing seasons. Seedlings may be lifted in either the fall or spring.

Antelope bitterbrush and other native shrubs have been grown at the Lucky Peak Forest Service Nursery near Boise, Idaho, during the past 10 years. Practices employed for native shrub production at Lucky Peak will be described where applicable throughout this paper.

SEED ACQUISITION AND PROCESSING

Purchase or Collection

Named varieties of several important native shrub species have been released for commercial seed production following extensive testing by the U.S. Department of Agriculture, Soil Conservation Service, and cooperating agencies (U.S. Department of Agriculture, Soil Conservation Service 1982). Seed of these releases is being produced under agricultural conditions in seed orchards or seed fields and is commercially available. The characteristics and range of adaptation of each named variety have been carefully determined. Production of shrub seed under agricultural conditions should result in improved seed quality and availability as appropriate cultural techniques are developed for each species. Other seed sources include plants of selected populations maintained at the nursery, collections from selected wildland stands, or purchases from commercial seed dealers. Seed source information should be provided with purchased seed. Acceptable purity levels for seed used for wildland plantings have been suggested by Plummer and others (1968). Acceptable germination levels are given in table 1. Seed transfer guidelines have not been established for native shrubs. For contract growing, seed of populations known to be adapted to the planting site should be obtained.

Precise timing is essential for the collection of seed from wildland stands. Maturation dates for individual shrub species range from May to February (U.S. Department of Agriculture, Forest Service 1974; Vories 1981; Wasser 1982). The exact seed maturation date for a specific wildland stand will depend upon its geographic location and local weather conditions. Species that ripen in late fall and winter must be collected nearly a year before fall sowing. Seed maturation in stands selected for seed collection should be carefully monitored. Expected crops may not develop and seed of some species such as antelope bitterbrush or snowbrush ceanothus (Ceanothus velutinus) is dispersed very quickly after ripening (U.S. Department of Agriculture, Forest Service 1974; Vories 1981).

Cleaning and Storage

Seedlots must be cleaned carefully to obtain high purity levels. Clean seed is required to maximize uniformity of seed placement and subsequent seedling development in the nursery beds. Sagebrush, rabbitbrush (Chrysothamnus spp.), and other species are often sold at low purities for rangeland seedings. Purchased seed of these species may require additional cleaning for nursery use.

Optimum storage conditions and the effect of various storage methods on the duration of seed viability have not been determined for most native plant species. Dry seed of sumac (Rhus spp.) and other species with water-impervious seed coats will remain viable for 10 to 20 years when exposed to ambient temperature and humidity conditions in open storage (Heit 1967; Hartmann and Kester 1975). Stevens and others (1981) found seed of antelope bitterbrush, fourwing saltbush (Atriplex canescens), and a number of other native shrub species to retain viability for at least 15 years in open storage. Fumigation or insecticides may be required to prevent infestation of open-stored seed.

Cold, dry storage increases the longevity of most medium to long-lived seeds and is desirable if seeds are to be stored for long periods. Seed should be placed in sealed, moisture proof containers and stored at 32° to 50°F (0 to 10°C). Below freezing temperatures (0° to 32°F [-18 to 0°C]) are most effective if the added cost is justified. The most effective moisture contents for cold, dry storage of native species have not been determined. Maximum safe seed moisture contents for cold, dry storage of many tree species is 9 percent. The relative humidity (R.H.) should be less than 70 percent and, if possible, less than 50 percent (Heit 1967; Hartmann and Kester 1975).

Cold moist storage (32° to 50°F [0 to 10°C]) at 80 to 90 percent humidity is required for such species as oak (Quercus spp.) and spring ripening maple species. Seeds of these species should not be allowed to dry prior to storage (Hartmann and Kester 1975).

Testing

Purity and germination or viability tests are used to provide an estimate of seed quality. Seeding rates are subsequently based on these tests plus determination of number of seeds per pound. Purity and seed weight are obtained following standardized procedures (AOSA 1981). Association of Official Seed Analysts (AOSA) standards for testing the germination of

Table 1.--Nursery production of native plant species

Species	Seed maturation dates[1]	Seed cleaning[2]	Acceptable purity (percent)[1]	Acceptable germination (percent)[3]	Duration of viability (years)[4]	Storage requirements[5,6,7]	Presowing treatment[8]	Stratification[5,6] Warm	Cold
								(numbers of days)	
Bitterbrush, antelope	6/25-8/15	4-2-4-5	95	90	16+	open or cold,[9] dry	none	none	60-90
Buffaloberry, silver	8/1-9/30	3-6-4	98	80	11-15	cold, dry	none	none	0-90
Ceanothus, redstem	7/10-8/15	6-4	98	85	16+	open or cold, dry	hot water	none	60
Chokecherry, common	7/25-9/15	3-6-4	98	70	4-6	cold, dry	none	none	120-160
Cliffrose, Stansbury	7/5-8/10	2-4-5	95	85	16+	open or cold, dry	none	none	30
Currant, golden	7/20-8/10	3-6-4-5	95	65	16+	dry, sealed	none	none	60
Dogwood, redosier	8/20-9/10	3-6-7-4	95	85	4-6	cold, dry	none	none	60-90
Elder, blueberry	8/15-9/25	3-6-4-5	95	50	16+	cold, dry	none	none	98
Ephedra, green	7/15-9/1	6-2-4	95	85	16+	open	none	none	none
Eriogonum, Wyeth	7/25-8/20	6-2-4	95	75	4-6	- - - -	none	none	none
Hawthorn, river	8/15-10/15	3-6-7-4	95	70	16+	cold, dry	H_2SO_4 (15 min. dry seed only)	none	84-112
Juniper, Rocky Mountain	9/1-12/30	2-6-4	98	60	16+	cold, dry	none	120	120
Maple, Rocky Mountain	8/1-9/30	2-4	90	85	0-3	- - - -	none	none	180
Mountain mahogany, curlleaf	7/10-9/1	2-4-5	90	80	16+	open or cold, dry	none	none	36
Rabbitbrush, rubber	10/15-12/30	2-4	10-15	75	0-3	open	none	none	120
Rose, Woods	9/1-11/30	3-6-4	95	70	16+	cold, dry	none	none	30-365
Sagebrush, big	11/5-1/15	1 or 2-4	8-12	80	4-6	- - - -	none	none	0-10
Saltbush, fourwing	10/20-3/1	1-4	95	50	16+	open	none	none	30-50
Serviceberry, Saskatoon	7/10-9/15	3-6-7-4	95	85	16+	cold, dry	none	none	120-180
Snowberry, common	8/10-9/15	3-6-4	95	80	7-10	open or cold, dry	H_2SO_4 (60 min)	20-60	60-300
Sumac, skunkbrush	6/20-10/10	3-6-4	95	40	16+	open or cold, dry	hot water	none	30-90
Winterfat common	9/25-11/25	2-4	50	85	0-3	cold, dry	none	none	none

[1]Purities listed are recommended minimum acceptable levels for rangeland seedlings (Plummer and others 1968).

[2]Key: 1. Hammermill; 2. Barley debearder; 3. Dybvig with water; 4. Two screen fan machine; 5. Gravity table; 6. Dry; 7. Seed grindermacerator. Jorgenson, K.; Stevens, R., Ephraim, UT: Data on file at Great Basin Experimental Area; 1982.

[3]Recommended minimum acceptable levels for rangeland seedings. Jorgensen, K.; Stevens, R., Ephraim, UT: Data on file at Great Basin Experimental Area; 1982.

[4]Open warehouse storage. Stevens and others (1981).

[5]Vories (1981).

[6]U.S. Department of Agriculture, Forest Service (1974).

[7]Heit (1967).

[8]Treatments used at Lucky Peak Nursery.

[9]Open storage - ambient conditions. Cold, dry storage - dried seed stored under refrigeration at 0° to 50°F (-18° to 10°C) in sealed containers (R.H. of 70 percent or less).

Table 2.--Nursery production of native plant species[1].

Species	Sowing date	Hand or broad-cast sowing	Pruning Top	Pruning Root	Lifting considerations	Production period	Persistent leaves	Vegetative propagation	Special considerations
Bitterbrush, antelope	Fall[2]				Lateral roots strip easily	1-0	X[3]		Treat seed with captan
Blueberry, elder	Fall		X	X	Thick taproot	1-0			Stratified seed germinates over 2-year period.
Buffaloberry, silver	Fall					1-0 or 2-0			
Ceanothus, redstem	Fall					1-0	X		Short seed collection period. Insect predation of seeds common. Seedlings subject to damping off, stem rot.
Chokecherry, common	Fall					1-0			
Cliffrose, Stansbury	Fall				Lateral roots strip easily	1-0	X		
Currant, golden	Fall					1-0		Hardwood cuttings	
Dogwood, redosier	Fall					1-0 or 2-0			
Ephedra, green	Fall, spring				Fragile roots	1-0			
Eriogonum, Wyeth	Fall, spring			X	Taproot	1-0	X		Insect predation of seeds common.
Hawthorn, river	Fall					1-0			Dry fresh seed several weeks prior to acid treatment. Seed lots frequently do not germinate uniformly.
Juniper, Rocky Mountain	Summer					2-0	X		
Maple, Rocky Mountain	Fall					1-0 or 2-0			
Mountain mahogany, curlleaf	Fall					1-0	X		
Rabbitbrush, rubber	Fall, spring	(X)	X	X	Large taproot	1-0		Wildings	
Rose, Woods	Fall					1-0			
Sagebrush, big	Fall, spring	(X)	X	X	Large taproot	1-0	X	Wildings	
Saltbush, fourwing	Fall		X	X	Large taproot, brittle stems	1-0	X		Low seed fill.
Serviceberry, Saskatoon	Fall					1-0			
Snowberry, common	Late summer, early fall					1-0 or 2-0		Stem cuttings	Warm stratification more effective than acid treat
Sumac, skunkbush	Fall				Large taproot	1-0		Root cuttings	
Winterfat, common	Fall, spring	X	X	X	Large taproot	1-0	X		Fluffy seed - not free flowing.
Willow, Scouler			X	X	Extensive root system	1-0		Hardwood stem cuttings	

1 Based on production experience at Lucky Peak Nursery.
2 Species normally sown in fall may be artificially stratified and sown in spring.
3 Normally deciduous, but may retain leaves in nursery.

individual native shrub species have not yet been established. Consequently, each seed laboratory has developed or adopted procedures for germinating commonly tested species.

Individual populations of a single shrub species may vary widely in germination requirements. In addition, the prolonged stratification periods required to release the dormancy of many shrub species (Vories 1981) decrease the usefulness of germination tests. Tetrazolium chloride tests of seed viability are frequently substituted for germination tests. At present, tetrazolium chloride test results for native shrubs are generally higher and more consistent than germination results, as not all viable seed will germinate under the less than optimum germination conditions provided.

Conditioning

Some native shrub species require presowing treatments to release various forms of seed dormancy (Heit 1971; U.S. Department of Agriculture, Forest Service 1974; Vories 1981; table 1). Acid or mechanical scarification, dry heat, hot water, hormone applications, and other chemical treatments are commonly used. The level of treatment required varies with accession and condition of the seedlot.

Dormancy requirements of many native shrub species are met by fall seeding. Heit (1968) found fall seeding of many dormant species fulfilled cold stratification requirements and provided increased seedling production, more uniform stands, maximum first year production, and less disease loss compared to spring sowing. He provided fall sowing recommendations for 55 shrub species. Species requiring moist, warm stratification may be sown during the late summer or early fall, watered, and covered with a layer of polyethylene or other mulching material. Artificially stratified seed of dormant species and seed of nondormant species such as rabbitbrush and winterfat (*Ceratoides lanata*) may be sown in spring.

Seed should be artificially stratified if it is unlikely that an adequate stratification period would be provided in the nursery. Artificial stratification is also an alternative if seed is not available at the time of fall seeding or when fall seeding is impossible due to weather conditions. Spring sowing also provides a means of controlling seedling size.

Sowing

Newly developed nursery drills such as the Love-Oyjord are capable of sowing seeds with a wide range of sizes and shapes. Seed must be carefully cleaned to facilitate uniform distribution and prevent clogging of the drill drop tubes. Seed of big sagebrush, which averages well over 2,000,000 seeds per pound (4,400,000 per kg) (Plummer and others 1968), for example, can be successfully seeded through such drills if first cleaned to a purity of 80 percent or greater. Other nursery drills that were developed for conifer seed are difficult to calibrate and cannot be used to sow small-seeded species.

Seeding Rate

Optimum seedling densities have not been established for native shrubs. Densities selected depend upon the species sown, geographic location of the nursery, size requirements for lifted seedlings, and other nursery conditions. Most shrubs grow rapidly compared to conifers and can be lifted as 1-0 stock. Fourwing saltbush, blueberry elder (*Sambucus cerulea*), big sagebrush and related species develop extensively branched shoot systems, large taproots, and spreading, lateral root systems, particularly when grown at low densities. Although they grow rapidly, species such as common chokecherry (*Prunus virginiana*) and curlleaf mountain mahogany (*Cercocarpus ledifolius*) usually produce one main shoot and only moderate sized root systems. Slowly developing species such as silver buffaloberry (*Shepherdia argentea*) and Rocky Mountain maple may be lifted as 2-0 stock and are normally planted at higher densities than species on a 1-0 rotation. Desired densities for native plant species range from 16 to 25 per square foot (172 to 269/m^2) at the Lucky Peak Nursery.

For many shrub species, the amount of seed required to produce a requested number of seedlings may be only estimated. Culling rates and seedbed mortality figures have not been established for individual species at most nurseries because too few seedlots have been sown to provide adequate data. In addition, these figures tend to vary with the seed accessions being grown. At the Lucky Peak Nursery, seedbed mortality for bitterbrush is estimated to be approximately 35 percent and the culling rate 15 percent. A seedbed mortality figure of 40 percent and culling rate of 20 percent are used for all other native plant species.

The following equation may be used to calculate the amount of cleaned seed required to grow a specified number of plantable seedlings. Data for typical seed lots and constants for production at the Lucky Peak Nursery were used to calculate the amount of seed needed to produce 1,000 plantable seedlings of antelope bitterbrush and fourwing saltbush.

$$\text{Wt. (lbs.)} = \frac{N}{(P)(G)(n)(1-M)(1-C)}$$

Symbols	Antelope bitterbrush	Fourwing saltbush
N = number of plantable seedlings required	1,000	1,000
P = purity (decimal)	.95	.95
G = germinability (decimal)	.90	.50
n = number of seeds per pound	21,900	58,000
M = seedling mortality (decimal)	.35	.40
C = culling rate (decimal)	.15	.20
Wt(lbs.) = weight of seed required to produce N seedlings	.10 lb	.08 lb

Seeding Depth

Shrub seeds vary in size from those of the common chokecherries (4,790 per pound [10 538 per kg]) to rockspirea (*Holodiscus discolor*) (5,340,000 per pound [11 748 000 per kg]) (Grisez 1974; Stickney 1974). Seeds should be sown at approximately 1.5 times seed diameter, or slightly deeper in light soils or for fall seedings (Williams and Hanks 1976). Small-seeded species are easily sown too deep. They should be drilled into shallow, open furrows and mulched lightly to regulate the planting depth.

Seed of shrubs such as winterfat and rabbitbrush do not flow freely. These and any other species that cannot be satisfactorily seeded with available equipment may be hand sown in drill marks and covered. Alternatively, seed may also be broadcast mechanically or by hand. Small seeds can be broadcast on a prepared seedbed and covered using a lightweight drag. The seedbed may be prepared using a roller, cultipacker, or other imprinter. Trashy or fluffy seed such as winterfat, rabbitbrush, Apache-plume, (*Fallugia paradoxa*), or western virginsbower (*Clematis ligusticifolia*) can be broadcast on an imprinted or rough surface. However, these seeds cling together and are not effectively covered with drags. They should be incorporated in the soil surface by running an imprinting implement such as a cultipacker over the seeded beds.

NURSERY CULTURE

Cultural requirements for most native shrub and tree species have not been determined. Practices in use include a combination of standard propagation techniques modified through on-site experience and observations of seedling development, growth rates, and morphological characteristics of individual species.

Mulching

Mulching fall-sown seedbeds reduces erosion, frost-heaving, drying, and crusting; protects seeds from cold; and reduces weed growth. Spring-sown seed may be mulched to retard surface evapotranspiration and regulate seeding depth. Well-watered seedbeds may be covered with a polyethylene film or any of a variety of materials commonly used as mulches (Hartmann and Kester 1975). Seedbeds may be rapidly covered by hydromulching. Mulch net, burlap, or snow fencing may be placed over the mulch to protect it from high winds. Mulches provide a uniform environment for overwinter stratification. They may be left in place to prevent premature germination where late frosts are a hazard. Rapid germination results when they are removed (Heit 1968; Hartmann and Kester 1975; Williams and Hanks 1976).

Irrigation

Once established, many species from arid sites require less irrigation than species from more mesic sites. Although it may not be possible to provide separate irrigation regimes for individual species, it may be possible to group species from similar vegetative communities within compartments or nursery fields.

Throughout the germination period, the soil surface must be kept moist to maximize seed germination and seedling emergence. This may be difficult to accomplish as the soil surface is subject to wide fluctuations in temperature and moisture supply. This problem is accentuated for small-seeded species sown at shallow depths and for seedlots with low germination rates and long germination periods. If a number of species are fall-planted without mulching, germination of individual species may occur at various times during a 2- to 3-month period. Fall or spring mulching of fall-sown seedbeds and removal of mulch after the danger of spring frosts has passed serves to minimize this problem by promoting more uniform germination, reducing the length of the germination period, and decreasing the length

of time the surface of the seedbeds must be kept moist. Fungal infections are of concern in the production of antelope bitterbrush, fourwing saltbush, mountain mahogany, and other native plants. Emergence may be enhanced by surface-sterilizing the seeds or dusting the seeds with a fungicide such as captan (Booth 1980). If seedling mortality is noted, water should be applied only sparingly.

Fertilization

Native plants are generally faster growing and less demanding of nutrients than conifers. If adequate nutrient levels are established before seeding, deficiencies of most elements are not likely to occur (Smith 1979). Nitrogen applications are usually necessary, particularly if high carbon-nitrogen ratios develop as a result of mulching. Conifers and shrubs normally receive similar fertilizer treatments at the Lucky Peak Nursery. Two thousand pounds per acre (2 245 kg/ha) of 6-2-0 Milorganite is incorporated into the soil prior to sowing. Ammonium nitrate (34-0-0) and superphosphate (0-46-0) are applied as side dressings.

Weed Control

Soil fumigants may be applied to nursery beds before shrub seeding to reduce weed problems. However, late August or early September fumigation with methyl bromide (98 and 67 percent) at 249 and 349 lbs/acre (280 and 392 kg/ha) followed by seeding of broadleaf species has produced unsatisfactory results in northern Plains nurseries (Riffle 1976). Poor seed germination and erratic growth during the first growing period following fumigation were attributed to decreased endomycorrhizal spores in the soil and endomycorrhizal development on seedlings (Riffle 1980). The use of fumigants such as Mylone that eliminate root pathogens but are not harmful to mycorrhizal fungi was recommended.

Most native shrub seedlings are weeded mechanically or by hand as herbicide recommendations are not available for individual species. Lohmiller and Young (1972) believed that herbicide recommendations established for agricultural species could be transferred to related wildland shrubs following simple testing. They found that preemergence herbicide techniques developed for peanuts and soybeans could be applied to several leguminous shrubs.

Several introduced hardwood species as well as antelope bitterbrush and common chokecherry have been included in the Western Forest Tree Nursery Herbicide Study (Abrahamson 1980; Ryker 1979). Ryker (1979) found postsowing and postgermination applications of bifenox reduced height growth of antelope bitterbrush and common chokecherry while postsowing and postgermination applications of DCPA were safe for common chokecherry. Enide has been used as a post-emergence herbicide for antelope bitterbrush at the Lucky Peak Nursery. Nursery managers should test promising herbicide treatments by applying them to test plots of individual species at the nursery site before large scale application (Sandquist and others 1981).

Pruning

Many shrub species grow rapidly, producing highly branched shoots (fourwing saltbush, big sagebrush) or shoots with numerous large leaves (blueberry elder, smooth sumac) during the first growing season. Large plants dominate smaller or later germinating seedlings, resulting in a lack of plant uniformity. Top pruning larger seedlings encourages more uniform growth and improves shoot/root ratios because smaller seedlings are released from competition. Top pruning early in the season promotes the development of larger branches on the lower stems (Williams and Hanks 1976). Seedlings may also be top or side pruned in the nursery during the dormant season or in the packing shed after lifting to provide a more desirable size for packing and planting.

Roots are pruned to increase seedling uniformity, stimulate fibrous root development, and improve shoot/root ratios. Severing the taproot of bitterbrush, fourwing saltbush, blueberry elder, and other species early in the growing season serves to stimulate lateral root growth. The fibrous roots that develop are stronger and less easily damaged during lifting. Pruning taproots of rapidly growing species one or more times during the growing season at increasing depths (for example, 4, 6, and 8 inches [10, 15, and 20 cm] also prevents the development of a thick root at the normal lifting depth. If these thick taproots are damaged during lifting, the open wound can easily be infected with disease organisms.

Lateral root pruning is used to increase fibrous root development, control seedling size and facilitate lifting. Roots of some species (for example, shrubby penstemon [*Penstemon fruticosus*]) may intertwine in the nursery bed and must be separated by hand during sorting.

SEEDLING HARVESTING AND STORAGE

Lifting

Shrub seedlings are frequently lifted in the spring, and usually break dormancy earlier in the spring than do conifers. They may also be lifted in the fall for immediate planting, when weather and soil conditions are favorable. Fall lifting and overwinter storage is a third option, especially for stock that must be planted early in the spring before weather conditions would permit lifting. Fall lifting and overwinter seedling storage also serve to reduce the spring workload and free bed space for sowing. Seedlings should not be lifted in the fall until they are adequately hardened by exposure to low temperature or frosts, or following leaf fall (Williams and Hanks 1976).

Species with fragile root systems or brittle shoots are easily damaged during lifting, packing, and planting. Plants that produce extensive root and shoot systems that have not been adequately pruned are bulky and difficult to pack and plant without damaging the plants or reducing survival.

Grading

Grading criteria have not been established for most native plant species. If possible, seedling specifications should be developed with the customer before sowing. Several factors should be considered in establishing specifications for individual species and orders. First, past outplanting experience may indicate morphological or size characteristics of seedlings that are correlated with transplanting success. For example, Carpenter (1983) recommends that only those antelope bitterbrush seedlings with branched stems should be used as this characteristic seemed to be indicative of an adequate root system for field planting (table 3). Second, seedling size requirements are related to planting site conditions; larger seedlings are generally required for more adverse sites. Third, size specifications may be modified to fit the proposed planting method. Seedlings with bulky root and shoot systems are difficult to plant using standard planting tools or mechanical tree planters. Fourth, customers may have individual preferences based on planting goals or past experience.

Table 3.--Grading and first year field survival of antelope bitterbrush seedlings at Lucky Peak Nursery. Nursery bed density 17.6 seedlings per square foot (180 seedlings/m²).

	Size Class		
Grading Criteria	I	II	III
Shoots			
length (inches)	4.7 (4-6)	6.5 (6-8)	8.8 (>8.0)
branching	branches <1/3 length of main stem	branches equal main stem length	branches equal main stem length
dry wt. (g)	0.5	1.2	1.9
Roots			
length (inches)	9.5 (8-10)	9.8 (8-10)	10.7 (10-12)
description	taproot - few short lateral roots	taproot - few lateral roots	taproot - few lateral roots
dry wt. (g)	0.4	0.8	1.0
Outplanting			
Percent of plantable seedlings	13	79	8
survival (percent)	88	88	90

Storage

Fall-lifted seedlings of deciduous species may be held in frozen storage at 28°F (-2°C) for extended periods. Seedlings must be protected from desiccation. At the Lucky Peak Nursery antelope bitterbrush and other shrubs may be fall-lifted for immediate planting at local sites. Seedlings not planted are packed in Kraft bags with polyethylene liners and stored in coolers at 28°F for spring planting (Carpenter 1983; Carpenter, personal communication). Fall-lifted seedlings with persistent leaves are subject to mold infection if held in cold storage and may be more successfully stored by "heeling in", although the success of this technique depends upon local weather conditions. At Lucky Peak spring-lifted shrubs are refrigerated at 32° to 34°F (0° to 1°C) in Kraft bags for periods of 1 to 3 months prior to planting.

VEGETATIVE PROPAGATION

Some species of native plants are more easily and economically produced from cuttings than from seed. Vegetative propagation is also used to maintain the genetic identity of stock with desirable characteristics. Such easily rooted species as willows (*Salix* spp.), poplar (*Populus* spp.), and cottonwood are often produced from hardwood cuttings. Oldman wormwood (*Artemisia abrotanum*), Absinthium (*A. absinthium*), willow (*Salix* spp.), and currant (*Ribes* spp.) have been grown from cuttings at the Lucky Peak Nursery.

Hardwood or semi-hardwood cuttings of the wormwood species root readily and may be collected and planted immediately without callusing. Cuttings may be made when the plants are dormant or during the growing season. Most species that can be propagated vegetatively in the nursery are grown from hardwood cuttings. Hardwood cuttings are inexpensive and are easily collected, handled, stored, and propagated. Cuttings may be collected from stands near the planting site or from cutting blocks maintained at the nursery. Cuttings are taken during the dormant period from healthy, moderately vigorous plants growing in full sunlight. Wood from the previous season's growth should be selected. Individual cuttings should include at least two nodes and may be from 4 to 30 inches (10 to 76 cm) in length and from 0.25 to 1.5 inches (0.6 to 3.8 cm) in diameter (Hartmann and Kester 1975; Williams and Hanks 1976).

Cuttings of species that do not root readily may be treated with a root-promoting substance such as indolebutyric acid, naphthaleneacetic acid, or indoleacetic acid. Indolebutyric acid at concentrations between 500 and 10,000 ppm (0.05 to 1.0 percent) is commonly used with higher concentration usually being more effective for hardwood cuttings. Fungicides such as captan or benomyl may be applied in combination with rooting compounds. Cuttings should be allowed to callus for several weeks

in cold storage before planting. Dormant cuttings are planted 2 to 4 inches (5 to 10 cm) apart within rows of the nursery bed with at least one bud above ground. They should be watered frequently as roots begin to develop. Willow, currant, wormwoods, poplar, and other rapid-growing species can normally be lifted as 1-0 stock.

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PRODUCING NATIVE PLANTS AS CONTAINER SEEDLINGS

Thomas D. Landis and Edward J. Simonich

ABSTRACT: Crops of native plants should be planned to allow enough time for seed collection, seed processing, seed treatments and stratification, greenhouse growth, and hardening. An ideal container nursery consists of a production greenhouse, a cold frame, a shadehouse and refrigerated storage. Four propagation methods can be used to produce native plants: direct seeding, germinants, transplants, and rooted cuttings. The choice of container should consider seedling growth, species characteristics and outplanting site. Most native plants can be grown reasonably well under a standard greenhouse environment and in commercial potting mixes. The type and amount of hardening will depend on the species characteristics and the future use of the plant. Nursery managers must be aware of variation between species, seed sources, and annual seed crops. Successful growers must acquire direct experience in producing each species under their own nursery system.

INTRODUCTION

The large scale production of native plants is still a relatively new enterprise and the growing of container seedlings in greenhouses is the newest production technique in western forest nurseries. Producing native plants in containers is a logical operation, however, because some species have proven difficult to grow as bareroot seedlings. For example, Mormon tea (*Ephedra* spp.) has very brittle stems and fragile root systems which are sensitive to breakage during bareroot lifting operations and the expansive root system of elderberry (*Sambucus* spp.) makes it hard to culture in seedbeds. Other native plants such as Arizona cypress (*Cupressus arizonica*) just seem to grow better in containers.

Container seedlings have been reported to have several advantages over bareroot seedlings such as a shorter production period and improved survival and growth after outplanting (Stein 1974). As already mentioned, some species are easier to grow in containers compared to bareroot stock and there is no root disturbance during seedling processing. On the outplanting site, container seedlings suffer less transplant shock and are generally easier to plant than bareroot seedlings. Instead of the limited spring planting period for bareroot trees, container seedlings have been successfully outplanted during the fall and may be suitable for other planting times as well (Stein 1974).

Although tree seedlings have been grown in containers for well over a decade, only a few nurseries are producing native plants as container seedlings. Compared to commercial tree species, very little is known about the culture of native plants in greenhouses. Many nursery managers are reluctant to try and grow natives because they have heard horror stories about the difficulty of breaking seed dormancy, and the availability and quality of native plant seeds have been unreliable.

The objective of this paper, therefore, is to discuss some of the cultural practices useful in growing native plants in containers. Because of their years of experience and good reputation in the field, the greenhouse operations of Native Plants Inc. of Salt Lake City, Utah, will be used as a model throughout the paper. Other pertinent literature will be referred to whenever appropriate.

PLANNING AND CROP SCHEDULING

Before the decision is made to produce native plants in containers, the grower should assess the potential market. This assessment requires business and marketing skills which are beyond the scope of this paper. Basically, though, there are two business approaches: (1) contract growing, or (2) speculation on future demand. Growing contracts are typically for a designated number of one or more plant species which are to be grown to certain size and quality standards by a specified time. Speculative growing is often risky and requires a keen appraisal of future markets. Some nurseries like Native Plants Inc. operate with a combination of contract and speculation growing.

The market analysis should result in a list of plant species to be produced. The grower must next decide whether the species can best be propagated by seeds or by vegetative cuttings. Seed dealers should be consulted to determine seed availability as some native plants do not produce a good seed crop every year and seed of some species does not store well. The grower must be certain that he can secure seeds or cuttings before proceeding with the planning process.

When the crop species have been selected, the grower should develop detailed production schedules that delineate the duration and sequence of the various operations (fig. 1 & 2). Crop planning is normally done during April or May so that there is enough time to secure seed later in the summer or early fall.

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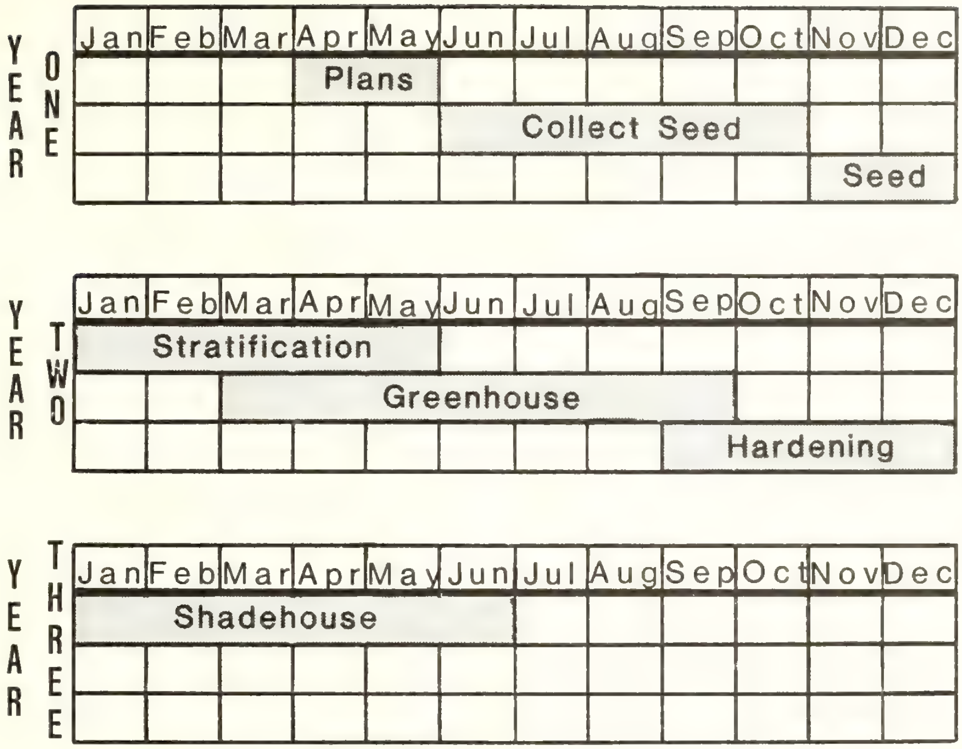

Figure 1.--Production schedule for growing native plants in containers: creeping Oregon grape (Mahonia repens)--germinants

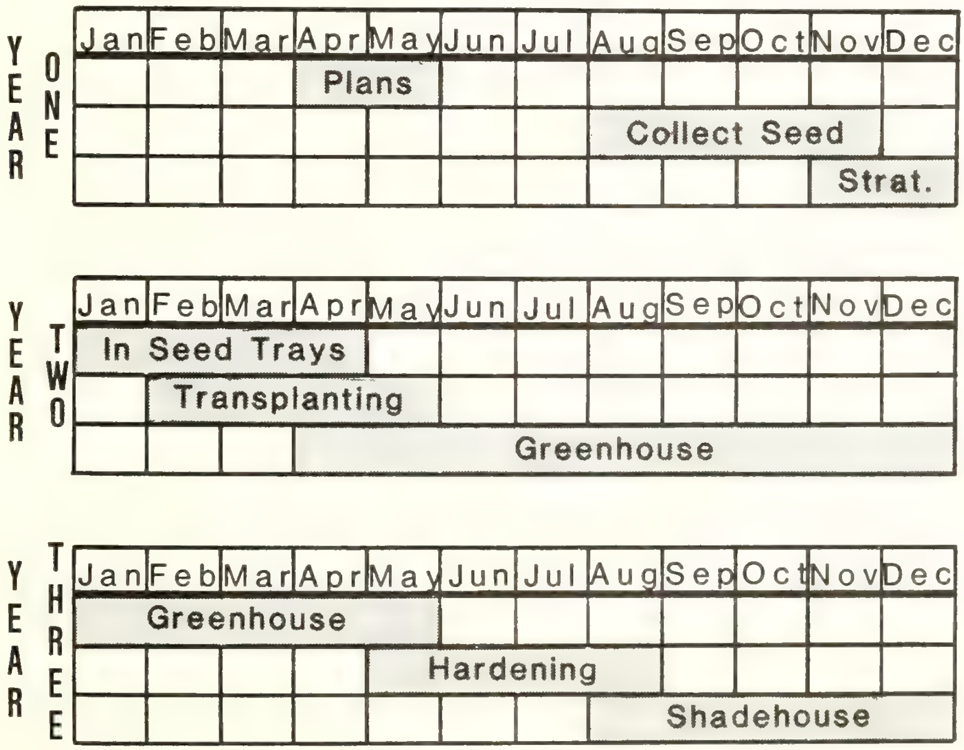

Figure 2.--Production schedule for growing native plants in containers: Rocky Mountain juniper (Juniperus scopulorem)--transplants

If seed must be procured, the total time for crop production may take from 2 to 3 years depending on the species of native plant and the type of propagation system (fig. 1 & 2). These rotation times are longer than for a typical conifer seedling which may take only from 8-12 months. The longer production period is primarily due to the problems with seed collection and processing and the extended stratification periods required for many native plant species. If seed can be obtained immediately, then the production time of some native species can be reduced to about 1 year. Most native plant seed can be collected and stored ahead of time although storability varies with species. Butterbrush (*Purshia tridentata*) can be stored under refrigeration for over 10 years, whereas prostrate summer cypress (*Kochia prostrata*) loses viability after one year (Steve Monsen, per. comm.). For planning purposes, however, it would be wise for new growers to allow ample time to grow their first crop of native plants.

Compared with many greenhouse crops where the plants are sold directly out of the production greenhouse, native plants must be properly hardened before they are suitable for sale. This hardening period will be discussed in detail later but normally requires at least 1 month.

PRODUCTION FACILITIES

Whereas many ornamental crops can be produced in a single structure, the greenhouse, native plants may require as many as four separate facilities. An ideal container nursery consists of 1) a production greenhouse to grow the seedlings, 2) a cold frame or shadehouse to harden the plants 3) a shadehouse to store the seedlings until they are sold and 4) refrigerated storage to maintain dormant stock for late season plantings. Native Plants Inc. has a three-structure system consisting of greenhouses, a cold frame, and an extensive shadehouse.

The best type of greenhouse depends on several factors but most important is the nursery climate. Most nurseries in the Intermountain area use fully-controlled houses which give maximum control over the environment whereas nurseries in milder climates may be able to use semi-controlled greenhouses. The advantages and disadvantages of different facilities are discussed in detail in Tinus and McDonald (1979).

One of the operational advantages of a fully-controlled greenhouse is the production of more than one crop per year; Native Plants Inc. is capable of producing two to three crops of plants per year depending on species. Some plants do not grow well during the winter season when day length is short and light intensities are low. Squawbush (*Rhus trilobata*) is very sensitive to photoperiod so crop lights are necessary to produce multiple crops (Steve Monsen, pers. comm.). Desert species just naturally grow better during the summer season.

The optimum size of greenhouse for producing native plants will vary, depending on the need for separate growing environments and the cost and operational difficulties of maintaining individual houses. Small, separate greenhouses permit the nurseryman to generate a range of environments and are also better for multiple cropping because species with different growing requirements can be sown and hardened at different times during the season. Separate houses allow more flexibility because the nursery manager can shut down some of his greenhouses and grow a smaller crop more economically. A single, large greenhouse can be designed with moveable curtains to produce compartments with different environments but the crop lights and irrigation system should also be under separate controls. On the other hand, larger houses are generally cheaper to heat and maintain, and less expensive to build than a range of smaller greenhouses.

PROPAGATION METHODS

The choice of propagation method is probably one of the most critical phases in native plant production. The majority of seedlings in forest nurseries are produced by direct seeding but the stringent stratification requirements and limited availability of many native plant seeds may require other approaches.

Native Plants Inc. uses four different methods to propagate woody plants in containers: direct seeding, germinants, transplants, and rooted cuttings (table 1). Some species such as pinyon pine (*Pinus edulis*) are only produced by one method (seed) whereas others such as common juniper (*Juniperus communis*) can be propagated by germinants or cuttings. The choice of propagation method also has its economic considerations. Direct seeding is the cheapest method because of a lower labor requirement compared to the rooted cutting technique which is more labor intensive and requires special facilities.

Direct seeding is defined as the sowing of seed into the growth container and is the standard technique for most conifer species and wildflowers. This propagation method is limited to those species with little or no dormancy requirement which works out to about 10 percent of the species produced at Native Plants Inc. The advantages and disadvantages of this method are given in table 1. If a stratification period or other pretreatment is specified, then the seed is treated prior to the planned sowing date. Otherwise, the seed is generally soaked in room temperature water for 24-48 hours and surface dried before sowing.

The seeding procedure begins with the calculation of the proper sowing density based on germination tests and past experience. Generally several seeds are sown per container and are later thinned to one seedling per cell. Because of the irregular shapes and sizes of most native plant seeds, most sowing is done by hand although a shutterbox or

Table 1.--Properties of four propagation methods for producing native plants in containers

Propagation Technique	Advantages	Disadvantages
1. Seeds - Direct sowing of seed to growth containers	· Quick · Minimal handling of seed · Sowing can be mechanized · Uniform crop development	· Hard to control cell occupancy and seedling density · Requires thinning and consolidation · Inefficient and costly use of seed · Greenhouse time lost prior to emergence
2. Germinants - Sowing germinated seed from stratification into growth containers	· Control of cell occupancy and seedling density · Efficient use of valuable seed · Good use of greenhouse space · Accommodates variable germination rates	· Sowing is slow and involves skilled labor · Irregular germination rate may cause variation in crop development · Number of seedlings subject to quality of seed lot · Requires specialized stratification chambers
3. Transplants - Seedlings are grown in trays and transplanted to growth containers	· Control of cell occupancy and seedling density · Efficient use of valuable seed · Good use of greenhouse space · More uniform crop development · Can use natural or artificial stratification	· Transplanting is slow and involves skilled labor · Requires additional operation of sowing seed trays · Overly dense seed trays could lower seedling vigor or lead to disease problems
4. Rooted cuttings - Vegetative cuttings are rooted in trays and transplanted to growth containers	· Control of cell occupancy and seedling density · Not dependent on seed crops · Good use of greenhouse space · Ability to preserve desirable genetic characteristics · Some species can be produced more quickly · Maintain sexual characteristics of dioecious species	· Transplanting is slow and involves skilled labor · Some species do not root well · Requires special facilities · Most costly technique

vacuum seeder could be used for certain species and large seed lots. The sown seed is usually covered with some type of material such as perlite or grit to hold the seed in contact with the potting soil and retard evaporation and algae growth.

The success of the direct seeding method is dependent on the accuracy of the seed information. Germination tests vary from lab to lab and no standardized tests are available for many native shrubs and forbs. Laboratory germination tests are run under ideal conditions and therefore test results may differ from greenhouse germination. Sometimes the seed is obtained just before the sowing date and so there is not enough time for seed testing.

The germinant technique is defined as the sowing of pregerminated seed into the growth container. This propagation method is best for plants with simple dormancy requirements and species with seeds too large to handle mechanically. It is particularly suitable for seed lots of variable or unknown quality because only good seed is sown in the growth container. Cell occupancy is maximized with this method as there are few blank cells and no subsequent thinning is needed. The germinant technique is used for about 15 percent of the native plant species produced at Native Plants Inc. The advantages and disadvantages are listed in table 1 and a sample production schedule is given in fig. 1.

The germinant procedure requires clean seed sc seed lots should be surface sterilized with chlorox or Captan to reduce molding during stratification. The seeds are usually hydrated with a 24-48 hour soak and then prepared for the stratification chamber.

Seed can be germinated in "naked" stratification where the bare seeds are kept in a plastic bag or mixed with a moisture-holding material such as peat moss. Native Plants Inc. uses a fine-textured, sterile peat moss, mixes the seed with the moss, and places the mixture in a plastic bag in a refrigerator at 30° to 40° F (-1° to +4° C). The acid peat moss helps retard seed molds during the lengthy stratification period which can last up to 8 months. The stratification bags should be checked at least weekly until germination begins. Seeds are ready to transfer to the growth container when a white radicle becomes visible but before the radicle becomes so long that it is easily damaged. Cracked seeds are not necessarily germinating; some species of seed swell and crack long before the radicle begins to emerge. Chokecherry (*Prunus virginiana*) seeds may take several months to produce a radicle after the seed intially cracks.

The planting operation consists of pouring the stratified seed out in a tray and picking out the germinants by hand or with tweezers. The germinants are placed in a depression or small hole in the potting soil in the growth container and covered with grit or perlite. Seeds should be placed with the radicle oriented downward; if the radicle is pointed upward it will reverse itself in response to gravity which may result in a stem crook in the young seedling. The crews at Native Plants' greenhouse have been able to achieve production rates of 1500-2000 plants per person-day using this procedure. It is a good idea to double sow the last couple of rows of containers in each tray to provide extra seedlings to transplant back into any empty cells.

Once all the germinants have been planted out of the tray, the seeds are placed back into the stratification bag and returned to the refrigerator. The planting crews go through the stratification bags three times per week until the germination rate begins to decline. These bags have been maintained for as long as 8 months for some species (eg. *Prunus* spp.) and germinating seed can be used as long as mold does not become a problem.

Transplants are the third propagation method used at Native Plants Inc. and account for 65 percent of the species produced. Transplants are defined as seedlings which are grown to the cotyledon stage in trays and then transplanted into growth containers. This propagation method is best for woody plants with complex dormancy requirements or for species such as quaking aspen whose small seeds would be almost impossible to plant by hand. This technique is ideal for seed lots of variable or unknown quality. A list of the advantages and disadvantages of the transplant method is given in table 1.

The transplant trays are filled about 2 inches (5 cm.) deep with standard potting mix and broadcast seeded by hand. Very small seed can be applied through a large salt shaker to ensure even seed distribution. Cover the seed with a light application of a fine-textured material such as sand-blasting grit.

The transplant trays are filled about 2 inches (5 cm.) deep with standard potting mix and broadcast seeded by hand. Very small seed can be applied through a large salt shaker to ensure even seed distribution. Cover the seed with a light application of a fine-textured material such as sand-blasting grit.

Seeds that require stratification are sown in the fall, irrigated, and placed outside in a sheltered location and protected against dessication. This outside storage allows the seed to naturally stratify over winter. When the trays are brought into the greenhouse in the spring, the seeds germinate readily and can be immediately transplanted. A growing schedule for this propagation method is given in fig. 2.

For seeds that do not require stratification, the transplant trays are taken directly into the greenhouse. In the greenhouse, the transplant flats are kept moist by frequent hand irrigation and germination usually occurs in 1-2 weeks. Once the seedlings grow to the cotyledon stage and begin to grow primary leaves, they are ready for transplanting. The transplanting procedure consists of working the seedlings loose from the soil, making a dibble hole in the potting soil of the growth container, and transplanting a seedling into the hole. The potting soil is then firmed around the seedling and the growth containers are irrigated and moved to the greenhouse benches. An experienced worker can transplant up to 2,000 seedlings in an 8-hour day.

When all the seedlings have been removed from the transplant trays, the soil is mixed, the trays irrigated, and the plants allowed to sprout again. Depending on the germination rate, the trays may produce up to three successive crops of transplant material.

Rooted cuttings are the final propagation method for native plant production. This technique consists of rooting vegetative cuttings in trays and transplanting them to growth containers. Approximately 10 percent of the species grown at Native Plants Inc. are produced by cuttings which is the best method for plants that are difficult to grow from seed or for which seed is difficult to obtain. The advantages and disadvantages of rooted cuttings are listed in table 1. At the Native Plants Inc. greenhouse, rooted cuttings are used as a last resort when the species cannot be reliably produced by another propagation technique; based on their cost figures, rooted cuttings are four to five times as expensive to produce as seedlings.

The production of rooted cuttings requires a special propagation facility which at Native Plants Inc. consists of a separate greenhouse with heated benches and a special misting system to control relative humidity. The cutting room is maintained at 70 to 75° F (21 to 24° C) and humidities approaching 100 percent. The atomized misting system is designed to maintain high humidities without overwatering the media in the cutting trays because fungal diseases quickly become damaging under saturated soil conditions. Supplemental lighting is used to extend normal day length and permit the production of rooted cuttings year round.

Cuttings are normally collected from plants in the field. The best season for collection depends on the species. Cuttings of two species of saltbush (*Atriplex cuneata* and *A. confertifolia*) rooted best when collected in spring or summer but the rooting percentage dropped markedly when cuttings were taken in the fall (Richardson and others 1979). Cuttings of some species such as big sagebrush (*Artemisia tridentata*) root better when collected during winter dormancy (Alvarez-Cordero and McKell 1979).

Native Plants Inc. currently collects most of their cutting material from "mother plants" which are older plants from the production stock at the nursery. To prevent disease spread, these mother plants are sprayed with a broad spectrum fungicide prior to collecting cuttings. Richardson and others (1979) reported that cuttings from greenhouse-grown plants rooted considerably better than field-collected cuttings for greasewood (*Sarcobatus vermiculatus*), a species that is normally difficult to propagate vegetatively.

A good step-by-step procedure for collecting cuttings is described by Norris (1983). Cuttings should be collected early in the day from new growth of active, healthy plants. Cutting the stem at an angle increases the surface exposure to increase new root production sites. All leaves should be removed from the lower third of the cutting and the cuttings should be kept in a shady, moist location. The crews at Native Plants Inc. prefer to plant the cutting the same day as it is collected.

Before the cuttings are planted, they are often treated with a special hormone to stimulate production of root primordia. These "rooting" chemicals can be made from scratch by mixing indolebutyric acid (IBA) with common talc, or you can buy commercial products such as Rootone or Hormodin. The best concentration of rooting hormone depends on many variables but, in general, the more difficult the plant is to root the higher the concentration of rooting chemical that should be used (Norris 1983). The rooting success of big sagebrush cuttings increased with increases in IBA concentration from 0.0 to 2.0 percent (Alvarez-Cordero and McKell 1979).

Treated cuttings should be inserted to a depth of 1 to 2 inches (2.5 to 5 cm) into a well-drained medium in a shallow rooting tray. The best media for rooting cuttings is subject to debate. Norris (1983) recommends a 1:1 ratio of peat to perlite or peat to fine sand. Native Plants Inc. uses different grades of sand and several combinations of sand, perlite, and potting soil. More information is needed on the best rooting media for different native plant species. Generally, the rooting medium does not contain any type of fertilizer because of a possible stimulating effect on disease organisms.

Some cuttings root quickly so it is important to begin checking the cuttings after the first week. Typically, the cuttings "callus-over" first and then produce adventitious roots from the callus tissue. Some cuttings such as those of juniper take as long as 6 months to root, so the cuttings should be inspected regularly for rooting or disease problems. Cutting success can exceed 95 percent with some species and Native Plants Inc. has achieved 75 to 100 cuttings per sq. ft. (6.9 to 9.3 per sq. m) of bench space.

The rooted cuttings should be transplanted immediately into a dibble hole in the growth container being careful to protect the new roots from injury. The transplanting procedure is inherently slower than any of the propagation methods using seeds but it is possible to reach up to a 95 percent success rate if the transplanting is performed conscientiously. The transplanted cuttings are grown under the standard greenhouse environment with special attention to irrigation during the initial period.

Another technique for producing cutting material involves the use of root sprouts. Species that regenerate by root suckers such as quaking aspen (*Populus tremuloides*) can be propagated by planting sections of lateral roots in an optimum environment and harvesting the succulent sprouts (Schier 1978). The excised roots are cut into 6 inch (15 cm.) sections and covered with potting media in a shallow tray and placed in the greenhouse. After several weeks, root sprouts will appear. These sprouts are cut off, treated with rooting hormones, and transplanted to a growth container. This technique is an effective way to propagate certain species but is quite costly in terms of the labor requirement.

PROPAGATION OF SELECTED NATIVE PLANT SPECIES

The propagation techniques used by Native Plants Inc. for 23 native plants are provided in table 2.

The stratification periods recommended in Seeds of Woody Plants in the United States (USDA 1974) illustrate the wide ecotypic variation in some species (e.g. Woods rose, 30-365 days) and lack of data for other species. The propagation methods listed are those most commonly used and some native plants can be propagated by more than one technique. Certain species are produced more easily during a particular season in the greenhouse whereas others can be grown any time during the year. Cropping time indicates the amount of time required to produce a saleable plant in the greenhouse and varies from 3-16 months.

GROWTH CONTAINER AND POTTING MEDIA

The best size, shape, and volume of growth container for producing a native plant that will survive and grow well in the field is a subject that is still open to debate. Ferguson and Frischknecht (1981) recommended a container that is 6 to 8 in. (15 to 20 cm) deep and has a volume of 15 to 25 cu. in. (245 to 410 cu. cm.). Barker and McKell (1979) grew four-wing saltbush (*A. canescens*) and greasewood in four sizes and types of containers ranging from 6 to 70 cu. in. (98 to 1147 cu. cm.) and found that shoot length, shoot biomass, and root biomass all increased with size of container.

Table 2 - Propagation procedures for selected native plants

Species	Stratification Period (Days)1/	Propagation Method2/	Production Scheduling Season3/	Production Scheduling Cropping Time (mos)
Acer circinatum, vine maple	120-240	G, T	Spring	4-5
Amelanchier alnifolia, serviceberry	120-180+	G, T, S	Any	3-4
Arctostaphylos spp., manzanita	0-210	T, C	Any	4-6
Artemesia tridentata, big sagebrush	0-10	T, S	Spr, Sum	3-4
Atriplex canescens, fourwing saltbush	30-50	T, S	Spr, Sum	3-4
Cercocarpus montanus, mountain mahogany	30-90	G	Any	4-6
Chrysothamnus nauseosus, rabbitbrush	0-120	T	Spr, Sum	3-4
Cowania mexicana, cliffrose	?	G, S	Spr, Sum	6-8
Ephedra viridis, Mormon tea	-	T, S	Summer	4-6
Juniperus scopulorum, Rocky Mountain juniper	240	T	Spr, Sum	12-16
Pinus monophylla, singleleaf pinyon	28-90	S	Any	8-12
Populus angustifolia, narrowleaf cottonwood	0	T, C	Summer	3-4
Populus tremuloides, quaking aspen	0	T, S	Spr, Sum	3-4
Potentilla fruticosa, shrubby cinquefoil	-	T, C	Any	3-5
Prunus virginiana, chokecherry	120-160	G, T, S	Any	3-5
Purshia tridentata, bitterbrush	60-90	G, S	Any	4-8
Quercus gambelii, Gambel oak	-	G, S	Fall	6-8
Phus trilobata, skunkbush sumac	30-90	G, S	Any	4-6
Rosa woodsii, Woods rose	30-365	T, C, S	Spr, Sum	3-5
Sambucus cerulea, blue elderberry	30-210	T, S	Spring	3-5
Shepherdia argentea, buffaloberry	0-90	T, S	Summer	4-6
Symphoricarpos oreophilus, mountain snowberry	60-300	T, C, S	Spring	4-6
Yucca glauca, yucca	0	S	Spring	4-6

1/ USDA-FS. 1974. Seeds of woody plants in the United States. Agric. Handbook No. 450. 883 p.

2/ S = seed; G = germinants; T = transplants; C = cuttings

3/ Spr = Spring crop; Sum = Summer crop

They concluded that, all other things being equal, these two native plants should be grown in the largest container possible.

The best container size for good field performance is not necessarily the best container for seedling growth in the greenhouse. Plants grown in large capacity containers generally perform best in the field but require too much greenhouse space and are costly to handle and ship. The best container also varies with plant species and environmental and soil conditions on the outplanting site.

Native Plants Inc. uses two different "tubepak" containers for most of their species: the 6-pack containers contain 13 cu. in. (213 cu. cm.) and the 5-pack has a capacity of 17 cu. in. (279 cu. cm.). Most species can be grown satisfactorily in the 13 cu. in. container but many broadleaved species have to be produced in the larger cells because their large leaves intercept irrigation and shade out adjacent seedlings. Some native plants such as elderberry (*Sambucus* spp.) and mountain-ash (*Sorbus* spp.) have massive root systems that require larger capacity containers. The density or spacing of the containers in the rack is also important because some species do not grow well at higher densities. Obviously, more work is needed to determine the best container to use for each of the native plant species.

Based on their experiences at the Native Plants' greenhouses, most natives grow quite well in standard potting mixes. Native Plants uses a mixture of equal portions of four materials: peat moss, vermiculite, perlite, and composted bark. They also incorporate a starter fertilizer mix (Osmocote 14-14-14) into the potting soil at 10 lbs. per cu. yd. (7.6 per cu. m.) and Micromax at 1.5 lbs per cu. yd. (1.1 per cu. m.)to supply micronutrients.

The potting mix should be near pH 5.5 and have an electrical conductivity (E.C.) reading of less than 2.0 mmhos.

Other researchers have reported on potting mixes for native plants. Ferguson and Monsen (1974) found that mixes containing peat moss and vermiculite produced better mountain-mahogany (*Cercocarpus ledifolius*) seedlings compared to those containing sand. The SEAM project at the Coeur d'Alene nursery produced 40 different species of native plants using a standard 1:1 mix of peat moss and vermiculite. Ferguson (1980) studied 39 different potting media and found that no one mix was consistently superior. He did report that a potting mix of 50 percent peat moss, 30 percent arcillite aggregate and 20 percent vermiculite is recommended for Bonneville saltbush (*A. bonnevillensis*) and possibly other plant species native to alkaline soils. Mixing native soil into standard potting mixes can increase growth of some chenopod species (Monsen, pers. comm.). A survey of nurseries growing desert shrubs reported a wide variety of potting mixes that contained such diverse components as sand, cinder, peat moss, composted bark, charcoal, sawdust, vermiculite, perlite, and native soil (Anon. 1979). Obviously, there is much variation in potting mixes but it appears that standard commercial potting soils are suitable for most native plants although special mixes may be desirable for some species.

GREENHOUSE CULTURE

Native shrubs have been found to grow well under normal greenhouse environments. Native Plants Inc. uses a uniform environment with day temperatures of 80°F (27°C), night temperatures of 65°F (18°C), a relative humidity of 30-40 percent, 800-1500 ppm carbon dioxide and a 24-hour intermittent photoperiod of 40 ft. candles. The SEAM project at Coeur d'Alene nursery maintained a greenhouse temperature of 65°F (18°C) for the entire growing cycle and intermittent photoperiod lights (20 sec. every 3 min.) at an intensity of 20-40 ft. candles. Monsen (pers. comm.) stresses that many native plants are very sensitive to photoperiod and so greenhouses should have continuous lighting systems.

Fertilization at the Native Plants' greenhouse is applied by two methods, Osmocote 14-14-14 fertilizer is added to the potting soil and Peters 20-20-20 soluble fertilizer is injected through the irrigation system. The injected fertilizer is not applied at any standard rate but is custom-applied based on experience. Because of the wide variation in nutrient requirements between the different native plant species, the grower must visually monitor the growth and color of the plants and fertilize based on experience.

Other greenhouse growers also emphasize the benefits of fertilization of native plants. The SEAM project applied all their nutrients through the irrigation system using a commercial 20-20-20 mix at a 1:100 injection ratio. This solution was applied weekly at the rate of 2 lbs. of fertilizer per 500 ft. (0.9 kg. per 46 sq. m.) of bench space. Once the desired top growth was achieved, the fertilizer mix was changed to a 15-30-15 mixture. Ferguson and Monsen (1974) grew mountain-mahogany seedlings with 3 different rates of Osmocote 18-6-12 slow release fertilizer ranging from 1 to 4 oz per cu. ft (34 to 102 g. per 0.03 cu. m.) of potting soil and found no significant growth differences between the rates.

THE HARDENING PHASE

The hardening phase is one of the most overlooked yet most critical periods in the growing cycle. It is relatively easy to produce an acceptable plant in the greenhouse but these plants are worthless unless they are properly conditioned so that they can survive and grow on the planting site. Many native plant species grow very rapidly under the optimal conditions in the greenhouse but this rapid growth consists of relatively large cells with thin cell walls and little tolerance to cold temperatures. Unlike most ornamental crops, native plants cannot be sold directly out of the greenhouse but must undergo a period of hardening. Ferguson and Monsen (1974) stated that the proper amount of cold hardening was one of the most difficult problems in the container production of native plants.

Hardening can be defined as the process in which growth is reduced, stored carbohydrates accumulate, and the plant becomes better able to withstand adverse conditions (Penrose and Hansen 1981).

There are three major objectives of the hardening phase:

1. To minimize physical damage during handling, shipping, and planting.

2. To condition the plant to tolerate cold temperatures during refrigerated storage or after outplanting.

3. To acclimatize plants to the outside environment and satisfy internal dormancy requirements of some species.

The type and amount of hardening depends on the individual species characteristics and the future use of the plant. Native plants produced as ornamentals usually require much less hardening compared to plants produced for a high elevation revegetation project. The two most important factors to consider in designing a hardening program are the planting date and the climate of the outplanting site. Most greenhouse nurseries are located at low elevations where the growing season begins earlier than at higher elevation planting sites. Native plants that will be planted in an environment that is similar to that where they were grown may only require a 4-6 week period of hardening. Plants that are outplanted at higher elevations during spring or fall must be able to tolerate colder temperatures and perhaps even frost.

Dormancy is another term that is often used in conjunction with hardiness. Dormant conifer seedlings have been shown to have the ability to produce abundant new roots when planted in a favorable environment. This high "root growth

capacity" should increase the ability of seedlings to survive and grow on harsh sites. The role of dormancy and root growth capacity has not been studied for most native plants. Plants stored under refrigeration for extended periods should also be dormant to minimize respirational heat build-up in the storage bags. Both dormancy and cold hardiness can be induced by proper scheduling of the hardening regime.

Hardiness should be induced in stages and the process usually takes at least 6-8 weeks. The hardening begins in the greenhouse by shutting off the photoperiod lights and carbon dioxide generators and leaching excess nutrients out of the potting media. Night temperatures are decreased and the seedlings are fertilized with a low nitrogen/high phosphorus and potassium fertilizer. Some growers also induce a mild level of moisture stress between irrigations which supposedly prepares the plant for the droughty conditions on the outplanting site. Drought stressing should be carefully monitored, however, because overly dry potting soil may be difficult to rewet and stressed plants may not cold harden normally. In the final hardening stages, temperatures are gradually lowered to the freezing level and tolerant plant species may even be taken slightly below 32°F (0°C).

Hardening can be achieved in either of two structures, a cold frame or a shadehouse. Shadehouses are generally used to harden crops that are taken out of the greenhouse in summer or early fall when freezing temperatures are not expected. The shadehouse consists of a frame structure that is covered with snowfence or shadecloth and is equipped with an irrigation and fertilizer injection system. Seedlings are protected from wind, intense sunlight, and light frosts in a shadehouse and usually continue to produce new roots and increase in stem diameter during favorable weather. The shadehouse also provides a good overwintering environment and such plants are well hardened by the following spring and ready for planting.

The cold frame used at Native Plants Inc. is a modified greenhouse structure which is maintained at low temperatures to promote hardening. Cold frame hardening is often necessary for crops that need to be removed from the greenhouse during freezing weather. Often, cold frames are used to induce dormancy and cold hardiness in plants before they are moved to a shadehouse for final hardening and storage.

VARIATION BETWEEN SPECIES AND BETWEEN CROPS

Although it is possible to grow several species of native plants under a standard greenhouse environment, nursery managers should be cognizant of the variable growth requirements and morphological characteristics of the individual species. A grower must directly experience how plants perform under his own nursery system before he will be able to consistently produce uniform crops of native plants.

Individual species will not grow the same during different growing seasons or during different years. Some species that grow best during the summer season will not perform satisfactorily if grown over the winter. Because of differences in seed crops from year to year and between seed sources, every crop of native plants will be slightly different in growth characteristics.

CONCLUSIONS

1. Crop planning is very important when working with native plants and a crop may take from 2 to 3 years to produce if seed is not immediately available.

2. Production of native plants may require as many as four separate facilities: production greenhouse, cold frame, shadehouse, and refrigerated storage.

3. Four propagation methods are used to produce native plants in containers: direct seeding, germinants, transplants, and rooted cuttings.

4. The best size, shape, and volume of growth container is dependent on the species of plant and characteristics of the outplanting site.

5. Standard potting mixes are adequate for many native plants but some species may require special mixes.

6. Native plants grow well under normal greenhouse environments but a grower should be aware of individual species differences.

7. Plants should be hardened in several stages by changing the growing environment and moving them to either a cold frame or shadehouse.

8. There is considerable variation between individual species and between seed collections and so each crop of native plants will perform differently.

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USE OF SHRUBS ON MINE SPOILS

Stephen B. Monsen

ABSTRACT: Mine disturbances can often be revegetated through natural plant succession. Plants that spread well by natural seeding can be used to seed mine spoils. Transplanting shrubs and herbs on mine sites hastens plant establishment and improves productivity and species diversity. However, shrub species differ in their ability to establish and survive as transplant stock. Therefore, planting sites must be prepared to accommodate direct seeding or transplanting. Environmental conditions of the planting site dictate the type of material and methods of planting. Existing herbaceous vegetation must be controlled to allow shrub seedlings to become established.

INTRODUCTION

Rehabilitation of mined land normally requires planting a combination of herbs and woody species. Natural invasion of native plants onto mined sites usually occurs too slowly to acceptably restore the site (McKell and Van Epps 1981). Planting is required to provide soil protection (Packer and others 1981), reduce the spread of weeds, and provide herbage and habitat to animals (Monsen and Plummer 1978).

Plantings also serve to establish a desirable and compatible array of species that will provide initial cover and ultimately develop a stable community (Laycock 1980).

Mined lands are generally harsh sites and plantings are not always successful. Seeding or transplanting may fail even when adapted species are used. Considerable differences exist between the microsites and soil conditions of mine spoils compared to undisturbed locations (Sindelar 1980). Consequently, it is difficult to determine the adaptability of individual species to mined land environments.

Species that are climax plants of undisturbed communities often are planted on mine spoils. Unfortunately, not all species that are regarded as climax, and usually considered desirable plants, are able to grow on disturbances (Eberly and Dueholum 1979; McGinnies and Nicholas 1980). Usually climax plants become established after the site has been modified by pioneer species. Many species that are initially adapted to mine spoils are considered weedy plants. These may persist for only a short time, but are useful to initiate plant succession (Stark 1966).

Species that are adapted to a wide range of soils, temperature extremes, and moisture conditions are the most successful species for harsh sites (Stark 1966). However, ecotypic differences occur within most species. Each ecotype is adapted to a particular range of conditions, and if planted within its natural range the selection will do well. If moved to unnatural conditions specific ecotypes often do not always survive (Plummer 1977).

Few plants have been specifically selected for their adaptability to mine disturbances. Only a limited number have been fully evaluated for their performance and survival on mine spoils. Most species that are currently used are native or introduced species that have been used mostly for other purposes. However, research has determined that certain species are adapted to infertile soils, and can be used on mined and associated disturbances (Stark 1966; Aldon and Pase 1981).

NATURAL INVASION OF PLANTS

Weedy annuals and short-lived perennial herbs are the principal species that invade most mined lands (Howard and Samuel 1979). However, some important woody plants also spread rapidly onto abandoned mines (Butterfield and Tueller 1980). Many plants are adapted to mine disturbances but spread very slowly by natural means. Invasion by plants is often hindered by factors related to seed production (Plummer 1977), seed germination, and seedling survival (Sabo and others 1979). The quality and quantity of seed produced on wildlands varies greatly and can be influenced by unpredictable climatic conditions and insects (U.S. Department of Agriculture 1974).

Winds, overland flow of water, and rodents are agents that carry seeds onto mine sites. Under wildland conditions rodents not only distribute but plant many seeds (West 1968). A high proportion of seed produced in wildland stands is consumed by animals including rodents (Bradley 1968). The excess is all that remains to perpetuate the species.

Rodents usually collect and store seeds of large fruited species and seed that consists of an edible endosperm. Usually, seeds that remain viable for an extended period are stored as caches in the soil surface by rodents for later consumption (Sherman and Chilcote 1972). Seeds planted as rodent caches frequently are not eaten but germinate later to form a cluster of new seedlings. Shrub seeds that are

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normally gathered and stored in caches include: antelope bitterbrush (Purshia tridentata), desert peachbrush (Prunus fasciculata), green ephedra (Ephedra viridis), Martin ceanothus (Ceanothus martinii), Saskatoon serviceberry (Amelanchier alnifolia), and Woods rose (Rosa woodsi).

Rodent activity is usually confined to areas offering overstory protection. However, rodent populations and habitat are not always decreased by clearing the vegetation (Turkowski and Reynolds 1970). Yet, small animals usually do not venture onto barren mine wastes or exposed sites. As sites become vegetated, rodents inhabit the area. Once plants that are established on the mine begin to bear seeds, rodents gather the fruits and help further the species and progress of successional stages in plant development.

A substantial amount of seed is produced by certain plants. Clean seed yields have exceeded 300 pounds per acre (338 kg/ha) for antelope bitterbrush grown on a planted site near Boise, Idaho. During years of high seed production many species increase dramatically due to the planting efforts of small rodents. Adapted shrubs and herbs can be selectively located on mined sites to provide rodent habitat, regulate their distribution, and thus advance the spread of select species.

Small seeded species and appendaged seeds are widely distributed by wind (Mirov and Kraebel 1939). Although a high proportion of weedy species is spread by the wind, many useful species are also dispersed by this method. Wind-carried seeds often spread plant species quickly, and populate otherwise inaccessible sites. Species that are successfully spread by wind include: Apache-plume (Fallugia paradoxa), sagebrush (Artemisia spp.), penstemon (Penstemon spp.), and rabbitbrush (Chrysothamnus spp.).

CONDITIONS INFLUENCING ARTIFICIAL SEEDING

Mined lands are usually planted soon after mining is completed. Disturbances primarily consist of overburden material or tailings composed of unconsolidated soil materials. Although topsoil and fertilizer may be added, mine spoils usually lack soil structure and particle aggregation that contribute to a optimum seedbed condition. Soil drainage, aeration, microorganism content, nutrient balance, and organic matter are all poorly developed for supporting a combination of plants (Frischknecht and Ferguson 1979).

Although fresh mine spoils are usually less productive than undisturbed sites, cultural practices often are not employed to improve tilth and productivity before planting. Therefore, planted species must be adapted to infertile sites, and capable of developing concurrently as young seedlings.

Grasses, broadleaf herbs, and woody species are often planted together. Assembly of a mixture of plants with different growth forms creates serious problems of competition among young seedlings. Mixed plantings favor herbs over shrubs and trees (Jensen 1980).

Grasses that are currently seeded on most mined sites are derivatives formulated for high germinability and seedling vigor. These highly competitive grasses develop much faster than do most native shrubs or trees. Grasses and many forbs not only germinate earlier than most shrubs, but attain a mature status much sooner. Most seeded grasses reach maturity in 1 to 3 years. In contrast, shrubs may require 5 to 10 years to attain a sufficient size to be fully competitive (Plummer and others 1968). During this interim, the developing shrubs are subjected to extensive competition, and plant losses are common (Booth and Schuman 1981). To be fully competitive with grasses, seeded shrubs and trees must possess the following traits: (1) seeds must germinate readily, (2) seedlings must develop rapidly, (3) seasonal growth periods should be compatible with the seeded herbs, and (4) developing plants must remain competitive.

Shrubs that can survive and develop satisfactorily by direct seeding are species that would not usually be grown as transplant stock. Some plants can justifiably be transplanted or direct seeded. Seeding is usually much cheaper and easier to accomplish. Some useful shrubs that can be successfully seeded include: basin big sagebrush (Artemisia tridentata tridentata), low sagebrush (Artemisia arbuscula), fourwing saltbush (Atriplex canescens), winterfat (Ceratoides lanata), snowbrush ceanothus (Ceanothus velutinus), rubber rabbitbrush (Chrysothamnus nauseosus), Wyeth eriogonum (Eriogonum umbellatum), prostrate summer cypress (Kochia prostrata), antelope bitterbrush, and thinleaf alder (Alnus tenuifolia).

Natural plant succession and edaphic changes that occur after mined sites are initially planted change the growing conditions and productivity of the disturbance. Some species that have been difficult to establish initially on fresh mine spoils by direct seeding or transplanting have been successfully established at a later date. New shrub and tree seedlings are frequently encountered as a result of natural reproduction, beginning 5 to 10 years after a site has been reclaimed. The encroachment often occurs on sites dominated by a competitive understory of herbs. However, the environment of some disturbances is so harsh that only a limited number of species establish and persist. Little improvement can be expected for a considerable period of time on these areas.

The success of most plants has been based upon the response attained from plantings established on newly exposed mine spoils.

Unfortunately many useful species are often discarded due to failures from initial plantings. Growing conditions improve as soil nutrients build up or the soil microflora is established.

VALUE OF TRANSPLANT STOCK

Although plants may be successfully established by direct seeding, transplanting is also a viable revegetation technique. Some species that establish readily by seeding do not grow rapidly enough to provide initial ground cover for soil stabilization (Shaw 1981). Some species that may fail to establish or perform satisfactorily by direct seeding can be transplanted. This has been particularly evident with Woods rose and chokecherry (*Prunus virginiana melanocarpa*) planted on phosphate mines in southeastern Idaho. Seedlings of both species germinated erratically and young plants were weak and slow to develop. Although plantings have been established on topsoiled and fertilized sites, the growth performance of these small seedlings has remained unchanged. However, 2-0 transplants of both species developed rapidly.

Transplants that are properly spaced can provide an immediate and effective cover. Transplanting can be effectively used to stabilize erodible sites and promote the natural establishment of understory species. Megahan (1974) reported that over 50 percent of surface erosion from roadfills was controlled by planting 1-year-old bareroot stock of ponderosa pine (*Pinus ponderosa*).

Transplants can also be used to control the establishment and spread of weeds. In contrast, shrub and tree transplants may also promote the establishment of some understory species. Ponderosa pine transplanted along steep roadcut and fill slopes in central Idaho stabilized the sites and served as a nurse crop for understory herbs (Monsen 1974). The presence of the overstory canopy of Woods rose, blueberry elder (*Sambucus cerulea*), and redstem ceanothus (*Ceanothus sanguineus*) also aids in the establishment of other species. Shrubs and trees that may persist for only a few years can be highly useful in the development of satisfactory cover.

Some leguminous and nonleguminous shrubs and trees are beneficial in improving soil nutritive levels. Klemmedson (1979) reported that eight genera of shrubs are able to fix nitrogen through actinomycete nodulation. These species can be used as companion plants to improve the performance of various understory herbs. Species of *Ceanothus* have been successfully used for this purpose on mine spoils in Idaho (Monsen 1974). Langkamp and others (1979) reported that reestablishment of a nutrient bank would occur slowly with the use of Acacia (*Acacia pellita*), and that pasture legumes would rapidly rebuild nutrient levels.

Transplants can be used to increase the rate of plant succession. In addition, transplant stock matures quickly and community changes occur rapidly. If persistent and compatible species are planted initially, a predesigned community structure can be arranged. This is an important feature, as many planted species do not attain full prominence until a mature and stable plant composition is achieved.

FACTORS AFFECTING TRANSPLANT SUCCESS

Factors that affect transplant survival are similar to those that influence seedling establishment. However, a significant difference is that transplanting usually eliminates the need for a prepared seedbed. The principal factors that reduce transplant survival are: (1) planting unadapted species and ecotypes; (2) carelessness in planting; (3) insufficient soil moisture resulting from inadequate site preparation and planting at the wrong time of year; and (4) use of poor quality planting stock.

Planting Adapted Species and Ecotypes

Species that are reared and planted on wildland sites in the West normally include selections that are native to the planting site. Seed and vegetative cuttings often are collected from the planting area. If this is not possible, stock is obtained from similar vegetative types growing in separate areas. In addition, various grasses, forbs, and shrubs have been developed for rangeland plantings.

However, few native or introduced species have been specifically developed for mined sites. Although numerous plants have been established on mined lands, their persistence and areas of adaptability have not been fully determined. Considerable differences have been recorded in the survival and initial growth rates of ecotypes when planted on mined sites. Different strains or ecotypes of many native shrubs could be used to select sources that have vigorous seedling adaptability to infertile soils.

Growers should be aware of the differences that occur among ecotypes of a particular species, and seek to raise stock that is adapted to specific soil and climatic conditions. Mined sites should be evaluated before planting to assure that adequate time is given to program the vegetation efforts, collect sufficient adapted seed, and rear transplant stock.

Plants that inhabit the site before mining may not be adapted to the mine spoils. Present State and Federal laws often require mining companies to restore native plant species to reclaimed areas. Although the use of adapted native plants is often advisable, many mined

sites are not capable of immediately sustaining the dominant species of the undisturbed site.

Some species and ecotypes are currently available that are adapted to mined lands, and these should be promoted and used. Research is needed to develop additional plants adapted to mined sites. A classification system needs to be developed to identify plant selections for disturbed situations. The system currently used in reforestation makes use of soil types, elevation, and climatic zones in selecting adapted ecotypes for planting. These features should also be applicable in delineating plants for mined lands, although the edaphic conditions of mine spoil are not entirely comparable to undisturbed soils. However, mining does not completely alter climatic and biotic influences. Consequently, plants that are components of original sites are still candidates for initial revegetation trials. Equally important is the identification of individual species that possess inherent characteristics that contribute to the range of adaptation of the species. For example, the occurrence of different subspecies, ecotypes, and kinds of sagebrush offers a wide diversity of planting stock suited to different site conditions (McArthur and others 1974). Through careful selection, adapted ecotypes of other species can be used to revegetate mine spoils.

Site Preparation and Planting

Transplanting does not require the intensive surface preparation treatment required for direct seeding, yet most mines usually utilize both revegetation techniques. Surface tillage and fertilization are required to enhance the survival of the seeded species. Seeding is frequently done to control soil erosion and surface runoff. Transplanting may be superimposed over the existing seeding. This usually does not create serious problems if transplant needs are recognized.

Transplants can usually compete with newly sown grass. However, if the grass is heavily seeded and fertilized, shrub transplants may suffer (Jensen 1980). Therefore, to improve shrub and tree survival the seeding should not be at a high rate. Fertilization of herbaceous species should be applied at a low rate, yet the seeding can be refertilized after the shrubs are well established.

Mine spoils should be treated to aid plant survival. Compact soils should be ripped to allow infiltration, aeration, and root development. Transplants should also be fertilized. Fertilizer tablets placed in the planting hole significantly aided tree growth in an Idaho trial (Megahan 1974).

Woody species that grow slowly and require 2 or 3 years to fully establish should be interspaced in strips or clearings separate from more competitive species (Giunta and others 1975). The planting areas should be delineated according to site conditions to assure that species are planted in adapted locations. It is not necessary to plant the entire site in a grid pattern. Species can be transplanted in groups, clusters, or mixes to provide diversity.

Planting Quality Stock

The development of high-quality transplant stock is essential to plant survival on mine wastes. Specimens that are poorly developed succumb quickly to adverse conditons. Failure to acquire and plant quality stock accounts for many planting failures.

Growers frequently produce a uniform grade of planting stock. Materials are grown to 1-0 or 2-0 size classes. Container-grown stock is also produced in rather uniform grades. Plants can be grown to different age and size classes, but this is difficult to program for a mine location when only a short rearing time is available.

The size and type of transplant is vital to plant survival. Species that grow rapidly will normally survive and grow well if a healthy 1-0 transplant is used. Other species grow slowly, requiring a year or two to fully establish and begin any appreciable growth. Green ephedra, mountain snowberry (*Symphoricarpos oreophilus*), mountain-ash (*Sorbus scopulina*), roundleaf buffaloberry (*Shepherdia rotundifilia*), skunkbush sumac (*Rhus trilobata*), and spiny hopsage (*Grayia spinosa*) do poorly when planted as 1-0 stock, but perform much better when planted as 2-0 or larger stock. Survival rates improve and growth is markedly increased.

Proper maintenance and field planting of a well-conditioned transplant is essential to plant survival. Shrubs such as Wyeth eriogonum, bush penstemon (*Penstemon fruticosus*), and prostrate ceanothus (*Ceanothus prostratus*) begin growth early in the season and must be lifted and planted as dormant stock, otherwise survival is very low.

Container-grown stock or ball and burlap materials are useful in planting rocky sites. However, high-quality bareroot stock will perform satisfactorily. Planting large pads and root sections as wildlings has proven successful with species of aspen (*Populus tremuloides*), oak (*Quercus* spp.), and other plants (Crofts 1978).

Mine plantings require special attention. Sites often are rocky and planting is impared. Without particular care, plants may fail simply because of poor handling. Care must be taken to follow normal planting guides.

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TOWARD PRODUCING DISEASE-FREE CONTAINER-GROWN NATIVE WILDLAND PLANTS

David L. Nelson

ABSTRACT: Methods and a fundamental philosophy for producing healthy planting stock of native wildland plants are presented. Drawing from the experience of agriculture, horticulture, and forestry, cultural and biological disease control methods are reviewed. The focus is placed on certification of planting materials, producing pathogen-free propagules, greenhouse design and management for disease prevention, controlling pathogens in plant growing medium, the role of native-host genetic variability, and managing biological control of soil-borne diseases.

INTRODUCTION

Interest is increasing rapidly in using native wildland plants to revegetate disturbed areas and improve wildlife and livestock ranges in the western United States. Producing healthy planting stock can enhance these activities. It is important to know when to take action in preventing and controlling diseases of plants. It is generally believed that if a disease is present it will be obvious and the plant will die, or if it does not die then it must not have a disease. A plant without obvious disease symptoms is not necessarily a disease-free or pathogen-free plant. There are also examples of viruses, bacteria, fungi, and nematodes that affect roots only slightly. The only visible injury is reduced top growth. Probably as much damage results from these "root nibblers" as from virulent pathogens that induce obvious symptoms and kill plants rapidly. Fungicidal treatment to prevent seedling diseases such as damping-off often only suppresses the pathogen which later induces further disease in the container plant or in the field after outplanting (Baker 1965).

A wise approach is to adopt rigid disease prevention methods regardless of present known disease problems. Currently, little if any research effort is directed toward controlling diseases in the production of wildland planting stock. The purpose here, therefore, is to relate facets of existing knowledge developed over the years in the horticultural and agricultural experience that may be of value in the wildland plant scene.

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Becoming aware is a major step in preventing plant disease problems. A long-standing principle in plant pathology is that action must be taken in advance to prevent disease problems. The goal of producing disease-free planting stock is also a responsibility, from a biological standpoint, that must be considered. There are several basic reasons for emphasis on producing disease-free planting materials. Clearly, the production of healthy planting stock is essential. It is important to avoid introduction of seed-borne pathogens to new field sites via planting stock. After outplanting, failure of the plant from a disease that did not express obvious symptoms during container culture is an important but more subtle problem. The responsibility to produce disease-free stock extends beyond the marketing stage of containerized plants.

How can an emerging native wildland plant industry organize itself to discharge this responsibility? Through an interaction of private, State, and Federal interests, an improved certification program should be developed. Certification of various plant attributes is already in progress at State and private concerns, plant introduction stations, and plant material centers across the West. The purpose here is to stress certification against plant disease. Benefits can be realized. Disease prevention should focus on certification in three basic areas: (1) seed-borne and vegetative-propagule-borne pathogens, (2) producing disease-free planting stock, both bare-root and containerized, and (3) a rigidly defined and controlled genetic base for seed collections.

Various methods have been used to prevent plant disease in container-grown planting stock. These methods have included seed certification, cultural sanitation, chemical seed treatment, pesticidal drenches, soil fumigation, heat treatment of planting media, vegetative propagule disease indexing, apical shoot tip culture, biological control, and pathogen suppressive growing media. These constitute a broad area of information; and this discussion will be limited primarily to cultural and biological means of producing disease-free, container-grown wildland plants.

CULTURAL CONTROL

Sanitation is the most important single guideline in the cultural control of plant disease problems of container-grown plants.

Sanitation is essential in the production, collection, cleaning, storage, and germination of seed. Sanitation also is an essential factor in maintaining greenhouse and shadehouse environments and in seedling transport and planting.

Pathogen-free Plant Propagules

Use of pathogen-free seed is an obvious first step in controlling diseases in container-grown plants as well as in nursery or direct field seeding. Several good references on seed-borne pathogens are: Baker 1956, 1972; Baker and Smith 1966; and Harman 1983. Plant pathogens may accompany seed independently as spores, resting structures, host debris, infested soil, and nematode galls. They may be carried passively, attached to the surface of seed or fruit parts, or they may be carried internally, imbedded in host seed tissue.

Seed dissemination of pathogens is a natural biological mechanism that has evolved as a mode of transmission in space, from season to season and from plant generation to generation. Seed-borne pathogens are not always transmitted, but when they are, they are usually a source of severe loss. Viruses are frequently seed transmitted. They usually infect gametes and persist during seed development. Mechanically transmitted viruses infest seed coats and are then transmitted to seedlings. Bacteria commonly infect developing embryos. They also enter the seed through the funiculus and reside in cavities of the seed coat or on outer layers of the embryo and endosperm. Fungi have numerous mechanisms for infecting seed and transmission to seedlings. The smuts of grasses invade embryos, and Fungi Imperfecti commonly infect seed coats and pericarps.

Injuries to seed during cleaning, for example, cracked seed coats, serve as entry points for both seed and plant pathogens and should be avoided. Pathogen propagules such as the sclerotia (ergots) of Claviceps and seeds of Orobanche and Cuscuta that accompany seed can be removed by separation during seed cleaning. Externally borne pathogens can usually be controlled by surface chemical treatment, but internally borne pathogens are more difficult to control requiring penetrating chemicals. To some extent thermotherapy has been successful in killing internally borne pathogens. Hot water, dry hot air, and aerated steam have been used effectively to eliminate pathogens. Aerated-steam treatment of seed has promising advantages (Baker 1969). Temperature can be controlled more accurately, seeds are left drier, there is less leaching, there is less damage to seeds, and the margin between pathogen thermal death point and seed damage is wider.

Prevention of seed-borne pathogens begins in the field with production of disease-free plants. Other methods include apical meristem culture, indexing and certification. Certification programs should be organized to establish tolerance levels for seed-borne pathogens. In the emerging native wildland seed industry what is the status of knowledge on seed-borne pathogens? Has action been taken to establish even the potential of what is inevitable? In the wildland scene a sound program must begin with gaining knowledge of seed-borne pathogens and their recognition by the collector.

Greenhouse design

Having achieved acceptable control of seed-borne pathogens, the focus can then turn to seed germination and growth of containerized plants in greenhouse culture. Commonly, if not almost universally, prevention of plant disease is not considered in the design of greenhouses. Here again, enhancing sanitation to reduce sources of contamination should be the guideline. Greenhouses and adjoining headhouses are seldom designed by persons with insight into plant disease prevention. Although elaborate systems can be devised to exclude pathogens for special purposes, relatively simple design considerations can make big improvements in routine operations.

Contamination can be avoided or greatly reduced if, in the headhouse, container and equipment cleaning and preparation and media treatment activities are in a room separate from container filling and planting activities. These rooms should be separated by a buffer room to reduce contaminate passage. A vestibule should join the headhouse and greenhouse planting growing rooms to allow independent access to rooms with distinct activities (fig. 1). The usual single-room thoroughfare type headhouses or separate buildings that require outside transport of materials to greenhouses are unacceptable because contamination is likely.

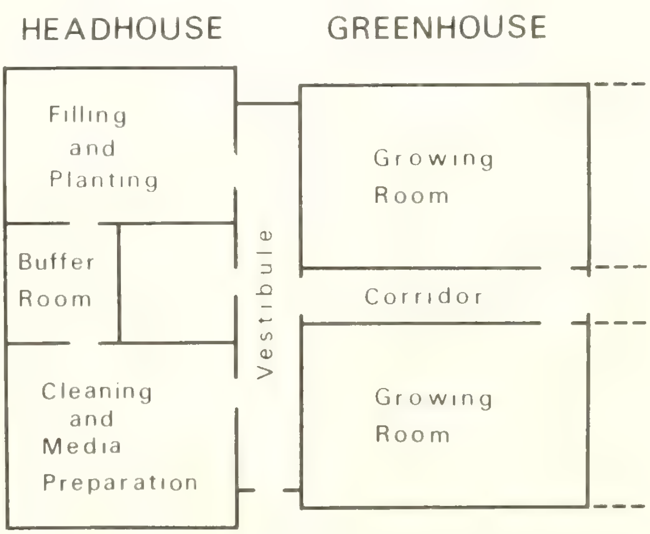

Figure 1.--Basic headhouse-greenhouse design for plant disease prevention.

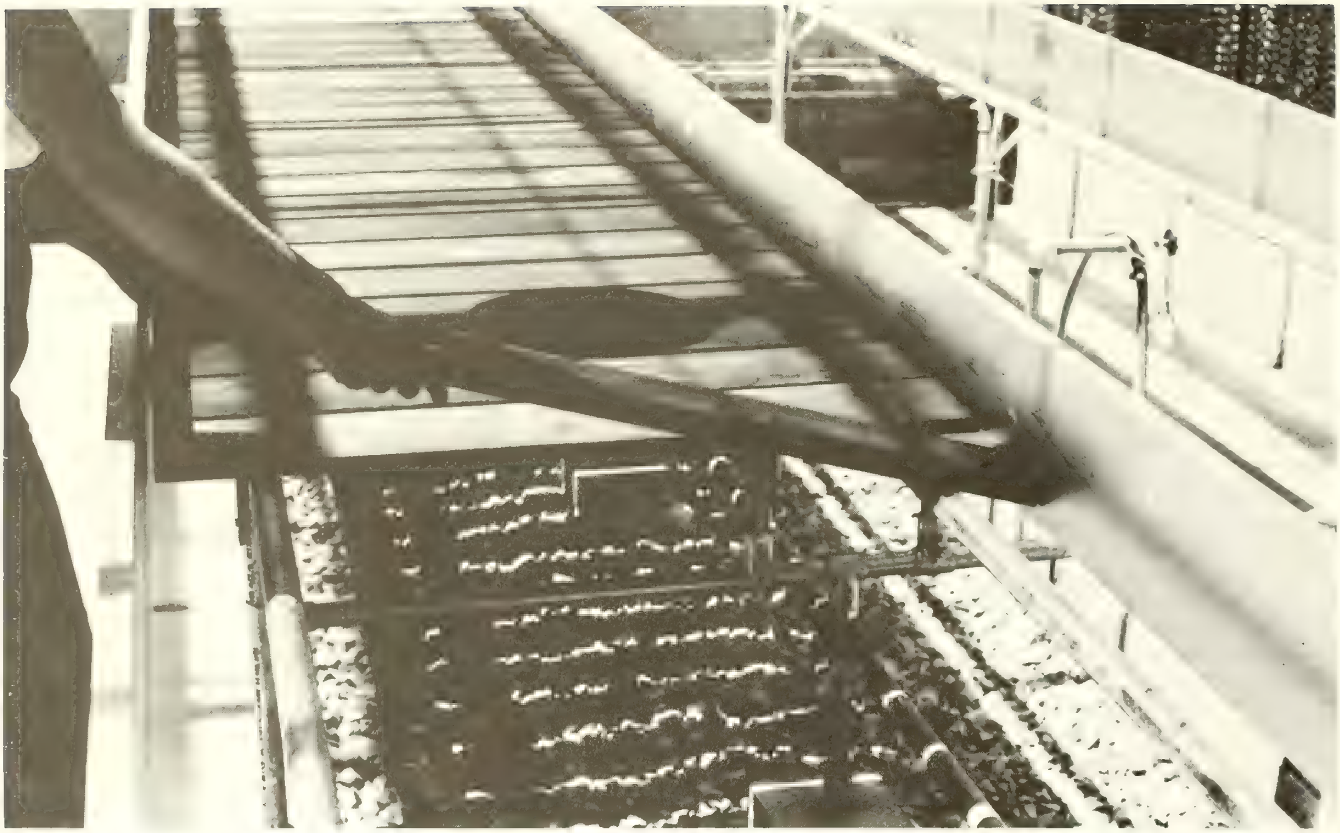

Figure 2.--A greenhouse bench designed to prevent plant disease. Note bench sides are not fixed to board support pipes, and removable boards act to minimize accumulation of debris.

Container filling and planting operations should not take place in greenhouse growing rooms because soil or other planting media spillage serves as an organic substrate for growth of pathogens on greenhouse floors.

Greenhouse benches come in almost every form and design imaginable and unfortunately many are conducive to creating disease problems. A well-designed greenhouse bench should feature a container support base that is independently supported from bench sides to avoided edges on which debris may accumulate (fig. 2). The base should also minimize areas where organic material can accumulate. The base should be easily removable for cleaning, decontamination, and treatment. An ideal system is to use removable boards impregnated with cooper-naphthenate. Periodically cleaning and treating boards achieves an essentially self-sterilizing base for containers (Baker 1957).

Watering Plants

Plant watering methods are a vital consideration in disease prevention. To begin with, containers are commonly overfilled with growing medium, leaving no reservoir for water. As a result, excess medium is then flushed from containers and accumulates under benches to provide an organic base for microorganisms. Individual watering nozzles should be hung up and not allowed to contact the greenhouse floor where they can become contaminated with disease-inducing organisms.

Container-grown plants are almost universally overwatered, which usually leads to seedling root rot problems. Wildland plants present a special problem in this regard because of their innate variability. Wide variation in germination rate, growth rate, and form requires selective watering. The nonselectivity of large automatic watering systems is a particular problem. Many desirable western U.S. native plants are adapted to semiarid environments and grow in soils with extremely low water potentials compared to the average domesticated ornamental. Little literature is available on the specific soil water potential requirements of seedlings. The role of soil water potential and the ecology of plant pathogens have been studied for some agricultural plant diseases (Cook and Papendrick 1970). Some unpublished data on wildland shrubs (Welch and others, USDA Forest Service, Shrub Sciences Lab., Provo, Utah), indicate that various species, sagebrush for example, grown in containers show little evidence of water stress even at -25 to -30 atmospheres. Visual judgment of the soil moisture a plant needs will probably result in overwatering. Critical measurement of soil moisture requirements is necessary to plan watering methods and consequently prevent disease.

Controlling Pathogens in Growing Media

Pathogen-free plant propagules and sanitary greenhouse management are of no avail without use of a controlled-pathogen growing medium. A vital component of native soil is the array of living microorganisms that exist in a dynamically fluctuating equilibrium. The system is controlled by the unique physical, chemical, and biological environmental characteristics of specific soil and vegetative types (Baker 1961; Elton 1958). The system is biologically buffered and permanent changes occur only with major environmental shocks. Such disruptions occur, for example, as a result of the numerous modifications incident to agricultural, greenhouse, or nursery operations.

Containerized plant growing media can be categorized as either containing soil or as soilless. The two types require different treatments to manage pathogens and retain proper biological and physical plant growth factors (Baker 1957, 1962a, 1962b). It cannot be assumed that soilless media ingredients, for example, peat, sawdust, ground bark, perlite, or vermiculite are or will remain pathogen-free. It can be more safely assumed that what these media do have are low or poorly balanced microorganism populations. Treatments to eradicate or control pathogens must contend with these unique features.

Fumigation of media with chemicals is a widespread practice, although there are attending disadvantages (Baker 1957, 1961, 1965). Toxic chemicals are difficult to contain in greenhouse operations and their use may become legally complicated in urban areas. Toxic residues may remain even after long periods of aeration. Fumigants move through the soil in a concentration gradient resulting in nonuniform treatment. Broad spectrum fumigants such as cloropicrin and methyl bromide tend to "overkill" and result in biological vacuums. More specific fungicides, for example , PCNB, Dexon, carbon disulphide, and Nemagon are available. However, pathogen populations are selected for resistance more rapidly by the more specific chemicals. Steam sterilization of media by heating to 212° F also results in biological vacuums. Both chemical and heat methods have the danger of recontamination. The drastically reduced competition in these treated soils results in rapid uninhibited growth of introduced pathogenic organisms. Loss to disease may be more severe than in untreated media. Phytotoxic compounds are also formed in soils that are treated at high temperatures.

Aerated-steam treatment of plant growing media avoids most of these problems (Baker 1962a). With this system, air is injected into the steam mass, producing a lower temperature vapor (fig. 3). By careful adjustment of vapor temperature, organisms can be selectively eliminated from the soil. Parasitic organisms tend to have more specialized enzyme systems than saprophytic organisms and thus tend to have lower thermal death points. Most weed seeds and many pathogenic fungi, bacteria, and viruses can be eliminated or inactivated in soil by aerated-steam treatment at 140° F for 30 minutes, leaving a beneficial population of microorganisms (fig. 4). Remaining fungi, bacteria, and actinomycetes then increase in number and antagonistic members act to inhibit invasion by contaminate pathogens. Fungistatic soil factors are initially lowered, but return to normal. Any phytotoxins produced are at low levels. Fire molds or "weed fungi" that grow profusely in sterilized soil are suppressed. The use of aerated steam is less expensive than steam sterilization because of the reduced temperature and treatment time required.

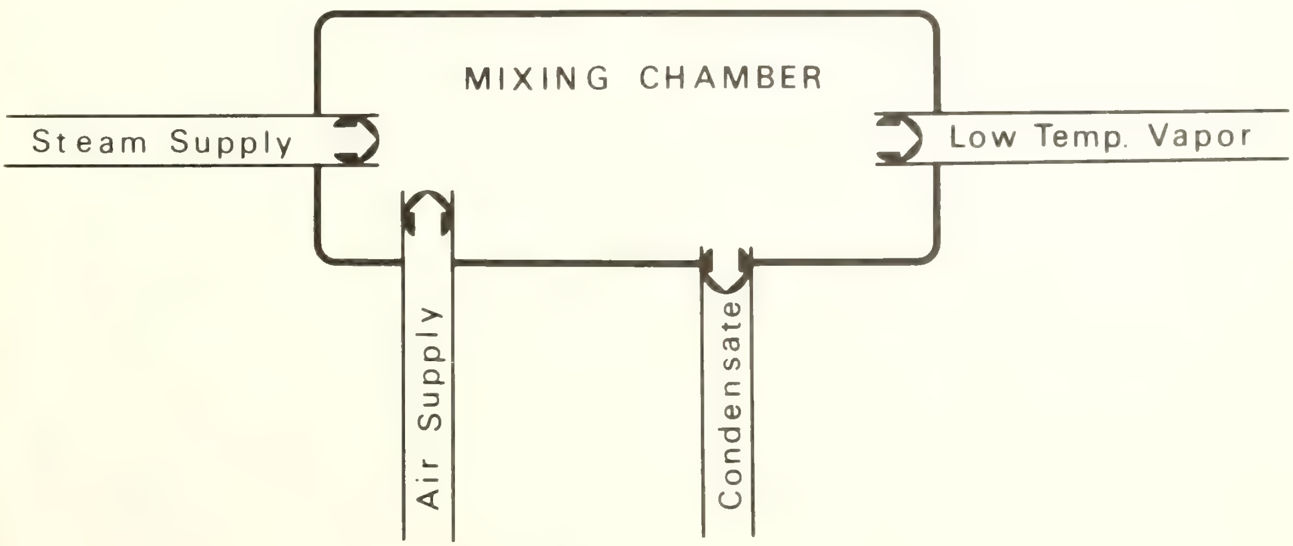

Figure 3.--Diagram illustrating the method of aerated-stream production for heat-treatment of plant growing media.

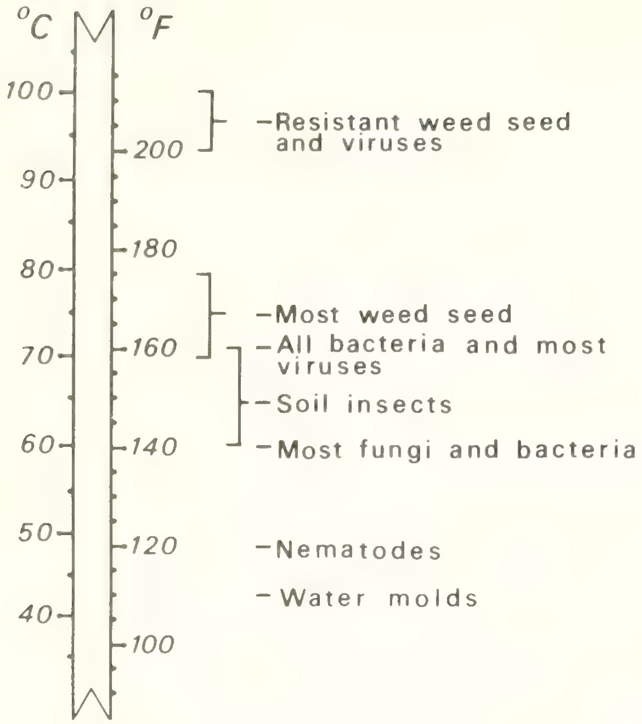

Figure 4.--Temperature scale illustrating the thermal death zones of plant pathogenic fungi, bacteria, viruses, and other soil organisms and weed seeds when subjected to moisture and heat, in most cases for 30 minutes (adapted from Baker 1957).

Aerated-steam treatment of soil is a prelude to and a valuable research tool in achieving biological control of soil-borne plant pathogens.

BIOLOGICAL CONTROL OF PLANT PATHOGENS IN CONTAINER MEDIA

The environment, host plant, and pathogen are not mutually exclusive. These three elements interact to result in plant disease. The host and pathogen are reciprocal biological environmental elements and also influence and are influenced by the physical environment. Cultural methods of managing plant disease are primarily directed toward manipulating the physical environment. The host plant, pathogen, and other biotic elements are the focus of biological control. The objective of biological control is not necessarily to eliminate disease, but to reduce it to a tolerable level.

Genetic Variability of Plants

Genetic resistance, tolerance, and susceptibility to pathogens are of fundamental importance in natural and manipulated biological control schemes. A basic difference exists in the genetic nature of wildland plants and domesticated plants. This is the native, relatively unaltered genetic variability of wildland plants. While this characteristic presents formidable problems for standardized cultural procedures, it is a virtue in providing disease resistance that must be rigidly protected. Variability is a basic factor in the survival and evolution of plant species. It must be protected at each step in the manipulation of native plants to be used for revegetation or range and wildlife habitat improvement. Methods used at each step must be studied carefully for impact on variability--from seed base selection, seed collection, seed cleaning, seed storage, pregermination treatment, and germination culture to seedling culture and plant establishment whether it be direct seeding or planting bare-root or containerized stock. Use of narrow line, vegetatively produced planting stock in wildland revegetation projects should be seriously questioned.

Cultural predisposition of container-grown plants to various pathogens is a two-fold problem in disease prevention. There could be loss from disease in containerized plant production or the potential for loss extended in time. If, for example, 50 percent of a native plant population is susceptible to a root rot when soil environment tends toward the anaerobic, one might predict predisposition to certain pathogens when container-grown plants are overwatered. The surviving population could then have a narrowed range of variability with which to confront their environment when outplanted.

To take advantage of naturally existing biological control systems now functioning in the wildlands of the West, it is important, in fact imperative, than an extreme effort is made to return revegetation plants (via containerized stock, bare-root, or seed) in near their native genetic state. Systematic seed collection methods need to be developed toward maximizing the preservation of the genetic amplitude of plant populations of interest. The plague of achieving disease resistance in agricultural plants has been the loss of native gene pools through the plant selection, improvement, and breeding sequence of domestication. Through history, plant pathologists and plant breeders have searched for lost genes by returning to native populations. Must the native wildland plant venture repeat the costly mistake of losing native variability?

Managing Biological Control

Biological control of soil-borne disease problems centers on manipulating antagonists and certain physical factors in the growing medium of container plants. Antagonistic activity occurs by parasitism, predation, competition for nutrients, and inhibitions from metabolic products of another organism (Baker and Cook 1974). Disease development may be

suppressed in certain soils even though both pathogen and susceptible host are present (Baker and Cook 1974; Liu and Baker 1980). Both biological and nonbiological factors are involved in these suppressive soils. Biological control and the nature of suppressive soil are at the forefront of current research on controlling soil-borne diseases of greenhouse and container-grown plants (Henis and others 1979; Chet and Baker 1980; Scher and Baker 1980).

With the aerated-steam treatment method already mentioned, certain pathogens, but not all pathogens, can be selectively eliminated from soil. The common spore-forming bacterium Bacillus subtilis Cohn emend Praznowski is retained and proliferates, producing rather specific antibiotics that are antagonistic to reinvasion by strains of Rhizoctonia solani Kuhn, a common pathogen of container plants (Baker and others 1967; Olsen and Baker 1968). The degree of specificity characteristic of this bacterium limits broad application. Strains of the ectomycorrhizal fungus Laccria accata (Scop.:Fr.) Berk. & Br. protect Douglas fir (Pseudotsuga menziesii [Mirb.] Franco) against Fusarium oxysporum Schlect. emend Snyd. & Hans., which induces a root rot of seedlings (Sylvia and Sinclair 1983). The disease is suppressed in soil-free systems but not in heat-treated soil. Seedling root growth, however, is also suppressed by cell-free metabolites of the fungus. Various soil-free formulations containing composted hardwood bark used as a growing medium are suppressive to Phytophthora cimmamomi Rands, Rhizoctonia solani, and Fusarium oxysproum, respectively root rot, damping-off, and wilt inducers (Hoitink and others 1977; Nelson and Hoitink 1983; Chef and others 1983). A dual mechanism has been suggested, attributed to antagonistic fungi (for example, Trichoderma harzianum Rifai) and heat-stable chemical inhibitors. Modification of soil factors such as pH and moisture levels can induce suppressiveness in a conducive soil. Parasitism of Rhizoctonia by Trichoderma is enhanced with these modifications.

Container growing media containing native soils have the advantage of a more diverse, complex microbiota than soilless artificial media. With complexity comes stability and a greater chance of biological control without modifications based on extensive research. With introduction of specific antagonistic fungi into sterile or soilless media to suppress specific pathogens there remains the risk of contamination and introduction of a second pathogen not influenced by the existing antagonists. In addition, the medium environment must be adapted to the selected antagonist. The potential for developing biological control with container-grown wildland plant diseases must exist. Existing natural systems must be studied. Disease inducing organisms and specific antagonists need to be identified.

One must conclude that no single disease control method is a complete answer, and so we hear terms like integrated control or a holistic approach--the battle goes on. Regardless and undoubtedly, sanitation and good housekeeping will continue to be in order.

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BIOLOGY AND MANAGEMENT OF BOTRYTIS BLIGHT

Robert L. James

ABSTRACT

Botrytis cinerea is an important pathogen of conifer seedlings in western North America, especially within greenhouses. Environmental conditions in greenhouses, such as high humidity and cool temperatures, are conducive to infection by and spread of this fungus. To reduce losses from Botrytis blight, cultural practices aimed at reducing inoculum and altering environmental conditions necessary for infection should be combined with rotated use of different fungicides. Several fungicides used to control Botrytis in the past are no longer effective because the fungus has developed tolerance to them. Fungicides commonly used to control this disease are discussed.

INTRODUCTION

Grey mold caused by Botrytis cinerea (Fr.) Pers. is one of the most damaging diseases of seedlings in forest tree nurseries. The disease is especially severe on containerized conifers in greenhouses where conditions are ideal for infection by and buildup of the fungus (James, Woo and Myers 1982; McCain 1978). However, Botrytis blight may also occur in seedbeds where it causes damage during cool, wet portions of the year (James 1980; James and others 1983). The fungus is also responsible for losses to seedlings in storage (Smith and others 1973).

Although many conifer species are susceptible to Botrytis, greatest damage has been reported on Douglas-fir, western hemlock, lodgepole pine, and spruce in British Columbia (Sutherland and Van Eerden 1980), western larch, lodgepole pine, and Engelmann spruce in northern Idaho and northwestern Montana (James and Genz 1983; James and Gilligan 1983; James and others 1982), lodgepole pine, Scots pine, Engelmann spruce and blue spruce in Colorado (Gillman and James 1980), and giant sequoia and Douglas-fir in California (McCain and Smith 1978).

BIOLOGY

Of the 22 species of Botrytis, B. cinerea, the one that affects conifer seedlings, is the most common and has the widest host range (over 200 plant species) (Jarvis 1980b; Sutherland and Van Eerden 1980). Other Botrytis species are more pathogenically specialized and thus have narrower host ranges.

A typical disease cycle for B. cinerea is shown in figure 1. Initial infection in nurseries results from spores produced on nearby infected plants or crop debris and from fungal resting structures (sclerotia) (Coley-Smith 1980; McCain 1978). Sclerotia often form after the growth phase of the fungus or following seedling mortality (Coley-Smith 1980). These sclerotia persist in soil, plant debris or within greenhouses and can produce both sexual (ascospores) and asexual (conidia) spores.

The sexual stage of the fungus is Botryotinia fuckeliana (DeBary) Whetzel, which has been found frequently in nature (Jarvis 1980b). Apothecia produced from overwintering sclerotia give rise to ascospores which may initiate infection (Jarvis 1980a). However, asexual conidia are responsible for most infection, spread, and buildup of the disease in nurseries.

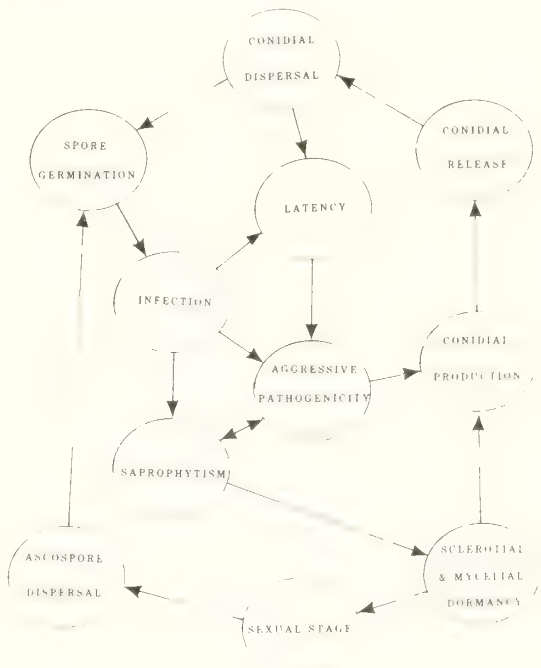

Figure 1.--Disease cycle of Botrytis cinerea (after Jarvis 1980a).

Conidia are dry and usually dispersed by air currents and less frequently carried by water droplets (Jarvis 1980a). Conidial dispersal occurs primarily when the relative humidity is rising or falling rapidly (Jarvis 1980a). Presence of free moisture on foliage for several hours and prolonged cool temperatures of about 13-14^{o} C are necessary for infection (Blakeman 1980). Germinating conidia form appressoria on the surface of leaves and germ tubes penetrate directly through the cuticle (Blakeman 1980). Wounded or necrotic

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[illegible] tissues are quickly infected and colonized (Sutherland and Van Eerden 1980).

Within the disease cycle, the fungus may become [illegible] (latent) following conidial dispersal and infection (figure 1). However, when inoculum is abundant and environmental and host susceptibility conditions are conducive, "aggressive pathogenicity" occurs (Jarvis 1980a). Conducive environmental conditions include high relative humidity, cool temperatures, and free surface moisture on foliage. Host susceptiblity factors include nutrient imbalances causing seedling stress and presence of senescent tissues for saprophytic buildup of inoculum (Sutherland and Van Eerden 1980). When conditions for infection are ideal and inoculum abundant, latent periods are short and epidemics can occur quickly (Jarvis 1980a).

Symptoms of Botrytis infection usually become apparent when crowns of conifer seedlings begin to close and affected seedlings usually occur in isolated pockets (Gillman and James 1980; James and others 1982). The fungus usually first attacks senescent tissues at the base of seedlings and then spreads to surrounding live host material (Smith and others 1973; Sutherland and Van Eerden 1980). Symptoms on infected seedlings include needle necrosis, twig and stem lesions, and mortality.

MANAGEMENT

Controlling Botrytis blight is difficult because the pathogen is capable of attacking all plant parts at almost any stage of their growth and in storage (Maude 1980). The best approach to control is to avoid conditions that are suited for disease buildup. This includes controlling stocking by reducing density to improve air circulation among seedlings (Cooley 1981), which means producing fewer trees per unit area. However, this is compensated by higher quality, disease-free seedlings. If possible, irrigation during periods of host susceptibility should also be limited (Cooley 1981). Adding drying agents to irrigation water to expedite drying of foliage may also help reduce infection. Fertilization should also be done properly. For example, too much fertilizer may cause seedlings to burn, providing ideal infection courts for Botrytis (Sutherland and Van Eerden 1980), and too little fertilizer may stress seedlings making them more susceptible to infection (Cooley 1981). Another important cultural practice to reduce loss from Botrytis blight is sanitation, aimed primarily at reducing inoculum. Sanitation practices include periodic removal of infected plants and plant debris, and cleaning greenhouse benches and floors with a surface sterilant between crops (Cooley 1981). Potential inoculum sources outside greenhouses, especially those upwind, should be eliminated when possible.

As containerized production of conifers has increased, Botrytis blight has become more important. As a result, many growers have had to rely on fungicides to keep losses at acceptable levels. Several fungicides either used operationally or showing promise for future use are listed in table 1. Some of the more important of these are discussed below.

Benomyl is a systemic fungicide that has been used operationally since the early 1970's. When it was first introduced, benomyl provided excellent control of many diseases over a wide range of crop plants. As a result, many growers began to use it exclusively to control Botrytis blight, especially in greenhouses (McCain 1978; Miller and Fletcher 1974). However, as early as 1971 tolerance to benomyl by Botrytis was evident (Bollen and Scholten 1971). Since then, there have been many reports of tolerance to this fungicide by different pathogens on a variety of crops including ornamental flowers, vegetables, fruit crops, and conifer seedlings (Cooley 1981; Gillman and James 1980; James and Gilligan 1983; Jarvis and Hargreaves 1973; Miller and Fletcher 1974). Simple tests have been developed to quickly assay presence of tolerant fungal strains. These involve growing the test organisms on nutrient media amended with the fungicide. Such tests have been used to evalute tolerance of Botrytis strains to benomyl and other fungicides throughout the West. Results indicate that tolerance of Botrytis to benomyl is so widespread that this chemical is usually ineffective and no longer recommended for use in most nurseries (Cooley 1981; Gillman and James 1980; James and Gilligan 1983).

Chlorothalonil is another fungicide that has been commonly used to control Botrytis in greenhouses. However, its ability to adequately control the disease has often been reduced, especially after continued use (James and Gilligan 1983). Recent tests indicate that some Botrytis populations in Oregon, Montana, and Colorado are tolerant to chlorothalonil (Cooley 1981; Gillman and James 1980; James and Gilligan 1983). Although tolerance to chlorothalonil is not as widespread as with benomyl, it is fairly common and has been shown to develop quickly in greenhouses (James and Gilligan 1983).

Captan is a general protective fungicide that is fairly effective against Botrytis (James and others 1982). However, tolerant strains to this fungicide have also been shown to exist (Cooley 1981; Gillman and James 1980; James and Gilligan 1983; Parry and Wood 1959).

Dicloran is an effective fungicide against Botrytis diseases (James and others 1982), even though tolerance of natural Botrytis strains has been found (Cooley 1981; Gillman and James 1980; James and Gilligan 1983; Webster and others 1970). Tolerant strains of the fungus can also easily develop in the laboratory (James, unpublished). Therefore, dicloran should not be used repeatedly unless rotated with other fungicides.

Two relatively new fungicides should also be mentioned. Iprodione was originally developed for turf diseases (Danneberger and Vargas 1982; Sanders and others 1978) and shows strong toxicity towards Botrytis (Pappas and Fisher 1979; Powell 1982). Vinclozolin is a chemical with specific action against Botrytis and related fungi (Pappas and Fisher 1979; Ritchie 1982). Iprodione has

been tested against Botrytis blight of conifers and shows excellent promise (James and others 1982). Vinclozolin was also tested, but showed extensive phytotoxicity to western larch seedlings at label rates (James and Genz 1983). Both fungicides require more field tests and need to be registered for use on conifers. Previous tests (Cooley 1981; James and Gilligan 1983; Leroux and others 1977; Pappas and others 1979) indicate that strains of Botrytis tolerant to ipriodione and vinclozolin exists, although not in large numbers. Tolerant strains can also develop rapidly to these fungicides in the laboratory (James, unpublished).

Apparently none of the fungicides currently available can be considered completely effective against all Botrytis strains likely to be encountered. As a result, fungicide useage should be limited to the minimum amounts necessary for effective disease control. Also, different fungicides should be used in rotation so as not to exert selective pressure on Botrytis populations to develop tolerance. Rotated fungicides should have different modes of action, i.e. systemic chemicals alternated with broad spectrum protectants (Cooley 1981; James and Gilligan 1983).

For effective control of Botrytis blight, cultural practices, such as better sanitation, providing adequate air circulation, and reducing irrigation, should be combined with rotated use of different fungicides. Cultural practices can reduce fungal inoculum and alter environmental conditions necessary for infection, whereas fungicides can protect susceptible plant tissues from infection. The combination of both procedures is necessary for an effective control strategy.

Table 1.--Fungicides used to control Botrytis blight in containerized conifer nurseries.

Fungicide	Trade names	Manufacturers	Chemical name
benomyl	Benlate® Tersan 1991 Benomyl	Dupont Lilly Miller	Methyl-1-(butylcarbamoyl)-2 benzimidazole carbamate
captan	Captan Orthocide®	Stauffer Chevron	N-[(Trichloromethyl)thio]-4-cyclohexene-1, 2-dicarboximide
chlorothalonil	Bravo 500® Daconil 2787®	Diamond Shamrock	Tetrachloroisophthalonitrile
copper	Tri-Basic®	CP Chemical Phelps-Dodge Cities Service	Basic copper sulfate
dicloran	Botran®	Tuco	2,6-Dichloro-4-nitroaniline
ferbam	Carbamate	Dupont	ferric dimethyldithiocarbmate
iprodione	Chipco 26019® Rovral®	Rhone-Poulenc	3(3,5-dichlorophenyl)-N-(1-methylethyl)-2,4-dioxo-1-imidazolidinecarboximide
mancozeb	Fore®	Dupont	Contains 16% maganese, 2% zinc and 62% ethylenebisdithiocarbamate ion/maganese ethylenebisdithiocarbamate plus zinc ion.
maneb	Dithane M-45®	Rhom & Haas	maganese ethylene bisdithiocarbamate
thiophanate-methyl	Zyban®	Mallinckrodt	dimethyl[(1,2-phenylene)bis(iminocarbonothyioyl)]bis (carbamate)
thiram	Thylate®	Dupont	Tetramethylthiuram disulfide
vinclozolin	Ronilan® Ornalin®	BASF Mallinckrodt	3-(3,5-dichlorophenyl)-5-ethenyl-5-methyl-2,4-oxazolidinedione
zineb	Zineb Dithane 278®	Rhom & Haas	zinc ethylenebisdithio-carbamate

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SALT TOLERANCE OF 10 DECIDUOUS SHRUB AND TREE SPECIES

Richard W. Tinus

ABSTRACT: Ten species of deciduous shrubs and trees were grown in a greenhouse and irrigated with nutrient solution plus sodium sulfate, chloride, and bicarbonate to yield salt concentrations with conductivity of 1.6, 4.5, 7.2, 12.1, and 16.6 mmhos/cm. Honeysuckle, crabapple, lilac, and American plum were salt sensitive. Buffaloberry, Russian olive, and chokecherry were moderately sensitive. Green ash, juneberry, and caragana were tolerant.

INTRODUCTION

Tree nurseries in western North America frequently have salt-affected soils and salty irrigation water (Tinus 1980). Salt creates an osmotic moisture stress that reduces germination and growth, and may kill seedlings. Without careful soil and water management, the problem gradually becomes worse until the nursery is no longer able to grow certain species that it formerly grew well. In the West, because shelterbelts are commonly planted on salty soils, careful choice of species is critical.

Very little quantitative information is available on salt tolerance of shrubs and trees grown for shelterbelts (Carter 1980; 1979). Most of what is available is on crop plants (Richards 1954; Branson 1978; Maas and Hoffman 1977; Rathert and Doering 1981) and horticultural varieties of shrubs and fruit trees (Bernstein and others 1972; Dirr 1974; Francois and Clark 1978; Maas and Hoffman 1977; Townsend 1980; Pasternak and Forti 1980). The objective of this study was to provide guidelines on salt tolerance of a variety of species commonly used for shelterbelts in the northern and central Great Plains.

METHODS AND MATERIALS

Experiment 1.--Seed Germination

Green ash seed was soaked 4 days in cold running water, caragana was used dry, and all other species were cold stratified in sand as recommended by Schopmeyer (1974).

Seed was germinated in petri dishes containing filter paper, 100 seed per dish, five dishes per species. Each of the five dishes per species was moistened with one of the nutrient solutions plus sodium chloride, sulfate, and bicarbonate listed in table 1.

The dishes were covered, enclosed in plastic bags to retard evaporation, and placed in a germinator with a 12-hour day (fluorescent light) at 30^{o} C and a 12-hour night at 20^{o} C. Humidity ranged from 60 to 100 percent.

Germinants were counted and removed every few days, and moisture was replenished as needed with distilled water. The experiment was terminated after 45 days. Total germination and germination energy (average percent per day to 50 percent of maximum germination) were calculated. Significant differences between salt levels within species were determined by Goodman's (1964) test.

Experiment 2.--Seedling Growth

Fifty Colorado State styroblocks, each with 30 cavities with a volume of 400 ml per cavity, were filled with 1:1 peat-vermiculite plus 5 percent forest duff to inoculate with endomycorrhizal fungi. Three seeds were planted in each cavity, five blocks for each of the 10 species. The blocks were arranged on greenhouse benches in randomized groups of 10, one block of each species. Each group was watered as needed with a nutrient solution plus sodium sulfate, chloride, and bicarbonate calculated to have an electrical conductivity (EC) of 1.6, 4.5, 7.2, 12.1, and 16.6 mmhos/cm (table 1). The soil salinity of the Lincoln-Oakes Nurseries at Bismark, N.D. (table 1) corresponds approximately to solution #2. The relative proportions of sodium sulfate, chloride, and bicarbonate were selected to be the same as in the irrigation water of Lincoln-Oakes, which has EC of 1,500 mmhos (about 1,000 ppm solids) and is rated "suitable for limited irrigation." Water supplies of other nurseries vary in composition considerably, but these ions are usually the ones causing the greatest problems.

After germination, the seedlings were thinned to one per cavity, leaving the largest. The remaining seedlings were allowed to grow 14 weeks. After this time, some of them were as large as they could be in the container without appreciable growth restriction, and differences between seedlings watered with different salt concentrations were clearly evident. The blocks of seedlings

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Table 1.--Composition of nutrient and salt solutions in parts per million

Component	Solution number 1	2	3	4	5
EC (mmhos/cm)	1.6	4.5	7.2	12.1	16.6
N as NO_3^-	229	224	220	211	202
N as NH_4^+	67	66	64	62	59
P as $H_2PO_4^-$	27	27	26	25	24
K^+	155	152	149	143	136
S as $SO_4^=$	142	139	136	131	125
Ca^{++}	212	208	204	195	187
Mg^{++}	48	47	46	44	42
Fe^{+++}	4	4	4	4	4
B as H_3BO_3	0.5	0.5	0.5	0.5	0.5
Mn^{++}	0.5	0.5	0.5	0.5	0.5
ZN^{++}	0.05	0.05	0.05	0.05	0.05
CU^{++}	0.02	0.02	0.02	0.02	0.02
Mo as $MoO_4^=$	0.01	0.01	0.01	0.01	0.01
Na^+	0	786	1,572	3,144	4,716
Cl^-	4	105	210	420	630
$SO_4^=$	0	922	1,844	3,688	5,532
HCO_3^-	0	732	1,464	2,928	4,392
TOTAL	889	3,416	5,943	10,998	16,052

were photographed and survivors were counted. Stem height and the length of two fully mature leaves were measured on each seedling.

For each species and measurement, a regression equation was calculated with height, leaf length, or survival as a function of salt concentration (measured by EC). Eight equation forms were tried using the Hewlett-Packard 9825A family regression program (General Statistics Vol. I, tape 09825-15004). The one with the highest r^2 was used to calculate the salt concentration at which growth or survival was reduced by 25 percent compared to growth or survival with nutrient solution only.

RESULTS AND DISCUSSION

Experiment 1.--Seed Germination

Russian olive and caragana germinated well at all salt concentrations, and neither total germination nor germination energy declined noticeably at high salt concentrations (table 2). Germination energy of buffaloberry declined steadily with increasing salt concentration, but total germination remained high through 12.1 mmhos/cm. Total germination of green ash and honeysuckle declined somewhat, and germination energy was greatly reduced by high salt concentration. Total germination and

Table 2.--Total germination and germination energy of seven species in nutrient solution with increasing concentrations of sodium chloride, sulfate, and bicarbonate. Within species values followed by the same letter are not different at the 5 percent level by Goodman's test.

Species	Total germination Solution conductivity (mmhos/cm)					Germination energy Solution conductivity (mmhos/cm)				
	1.6	4.5	7.2	12.1	16.6	1.6	4.5	7.2	12.1	16.6
	- - - - - - - - - - percent - - - - - - - - - -					- - - - - - - - - percent/day - - - - - - - - -				
Lilac (_Syringa_ _vulgaris_ L.)	73 a	54 b	40 c	19 d	1 e	1.63	1.13	0.82	0.33	0.02
Crabapple (_Malus_ _baccata_ (L.) Borkh.)	40 a	24 b	12 c	4 d	3 d	1.23	0.56	0.32	0.09	0.06
Honeysuckle (_Lonicera_ _tatarica_ L.)	33 a	30 ab	22 b	6 c	5 c	0.79	0.94	0.76	0.24	0.22
Green ash (_Fraxinus_ _pennsylvanica_ Marsh.)	88 a	71 c	80 b	61 d	58 d	4.2	2.7	2.9	2.0	1.4
Caragana (_Caragana_ _arborescens_ Lam.)	87 b	96 a	85 bc	75 c	89 ab	5.4	4.8	7.1	3.5	3.5
Russian olive (_Eleagnus_ _angustifolia_ L.)	84 c	94 b	100 a	62 d	82 c	10.4	7.4	8.1	4.7	6.5
Buffaloberry (_Shepherdia_ _argentea_ (Pursh) Nutt.)	90 a	91 a	78 b	86 a	66 c	11.3	9.7	8.4	6.5	2.6

Table 3.--Salt concentration (measured by conductivity) causing a 25 percent reduction in growth or survival, compared to nutrient solution with EC of 1.6 mmhos/cm

Species	Height	Leaf length	Percent survival	Regression quality (r^2) Height	Regression quality (r^2) Leaf length	Regression quality (r^2) Percent survival
	- - - -	mmhos/cm	- - - -			
Honeysuckle (*Lonicera tatarica* L.)	2.2	3.3	3.3	.55	.32	.71
Crabapple (*Malus baccata* (L.) Borkh.)	2.6	6.0	--[1]	.54	.67	NS
Lilac (*Syringa vulgaris* L.)	3.6	4.1	15.7	.70	.71	.92
American plum (*Prunus americana* Marsh.)	6.3	7.1	5.0	.35	.78	.69
Buffaloberry (*Shepherdia argentea* (Pursh) Nutt.)	7.6	8.2	>16.6	.33	.29	.33
Russian olive (*Eleagnus angustifolia* L.)	8.3	>16.6	>16.6	.30	.18	NS
Chokecherry (*Prunus virginiana* L.)	8.7	9.6	>16.6	.30	.60	NS
Green ash (*Fraxinus pennsylvanica* Marsh.)	11.7	8.6	>16.6	.42	.30	NS
Juneberry (*Amelanchier alnifolia* (Nutt) Nutt.)	11.8	14.5	>16.6	.51	.36	NS
Caragana (*Caragana arborescens* Lam.)	>16.6	5.1	>16.6	.07	.23	NS

[1] Regression equation not meaningful.

germination energy of crabapple and lilac declined precipitously with the first increment of salt, and germination was almost nil at 16.6 mmhos/cm.

Experiment 2.--Seedling Growth

Table 3 lists the 10 species tested in order of increasing salt tolerance as measured by height growth. As expected, leaf length was reduced by about the same degree as stem height (Sepaskhah and Boersma 1979), except that leaf length response of Russian olive was more nearly in keeping with field observation than height response. Russian olive has a reputation for being highly salt tolerant. Bernstein and others (1972) report that the salt tolerance of a related species, silverberry (*Eleagnus pungens*), is also high; the threshhold for reduction of growth in silverberry is 9.4 mmhos/cm. Caragana also showed high salt tolerance when measured by height reduction, but not when measured by leaf length. It is possible that reduced leaf length is part of the species' adaptive reaction to moisture stress. This agrees with field observations because caragana flowers and grows vigorously in early summer, when moisture is normally adequate, but yellows and begins dropping its leaves in August, when moisture stress is frequently high.

As with germination, height growth and leaf length of honeysuckle, crabapple, and lilac decreased rapidly with increasing salt. Maas and Hoffman (1977) also report that apple (*Malus sylvestris* L. Mill) is salt sensitive. American plum was sensitive, as expected, in comparison with *Prunus domestica* (Richards 1954; Maas and Hoffman 1977), but chokecherry (*Prunus virginiana* L.) was surprisingly tolerant, especially with respect to survival.

Once established, most species survived well at much higher salt concentrations than were required to suppress growth. Exceptions were honeysuckle and American plum. Survival information is thus useful to tree planters for site selection, but

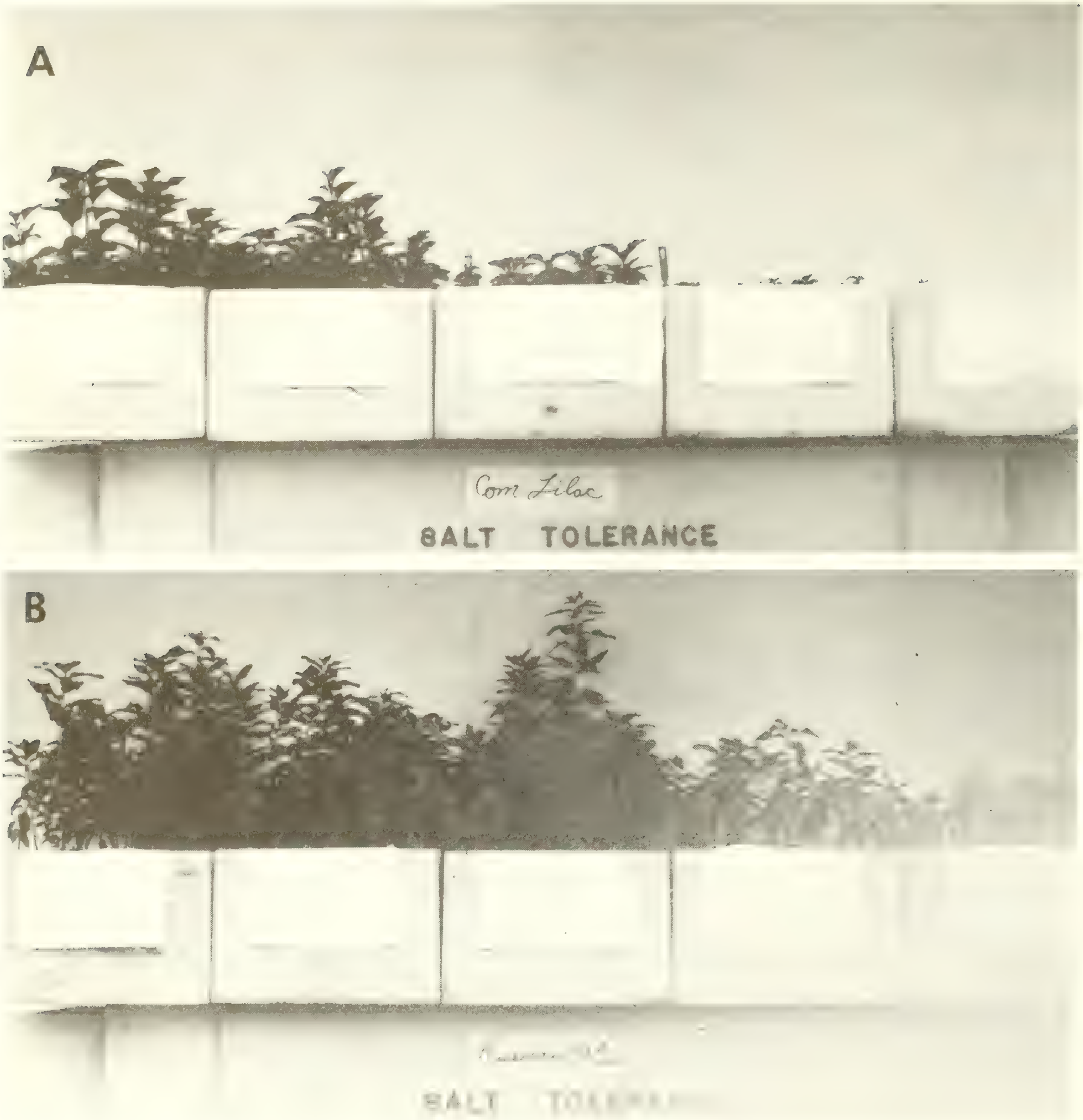

Figure 1.--Decreasing growth with increasing salt concentration (measured by EC) of (A) lilac, a salt sensitive species and (B) Russian olive, a salt tolerant species.

not to nurserymen, whose product must reach a certain size within one or two growing seasons.

Because of the need to keep this experiment small and simple, only one germinating dish of 100 seed and only one block of 30 seedlings per species per treatment was used. For statistical purposes, the individual seed or seedling was treated as the unit of replication. Strictly speaking, however, there was no replication. Furthermore, variability was great, and the regression equations used yielded confidence limits so great that only the broadest comparisons between species can be made. Thus, although the results were quite obvious even without measurement (fig. 1), they should be considered indicative and not definitive.

CONCLUSIONS AND RECOMMENDATIONS

1. Crabapple, lilac, American plum, and honeysuckle are sensitive to salt. They should not be grown at a nursery with salty irrigation water or soil nor outplanted into salty soils.

2. Buffaloberry, Russian olive, chokecherry, green ash, juneberry, and caragana are salt tolerant. Their growth should not be limited at most western nurseries because of salt problems, and they should be able to tolerate the saltiness of most western soils where shelterbelts are planted.

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CONTAINERIZED SEEDLING PRODUCTION FOR FOREST REGENERATION IN THE PACIFIC NORTHWEST

James M. Sedore

ABSTRACT: The containerized seedling continues to be a valuable regeneration option during this time of economic stress. Recent developments in plug-1 culture and seedling storage are described.

INTRODUCTION

As you know, these are hard times for the timber industry. The lack of timber harvesting has reduced the demand for regeneration seedlings. Seedling orders have been reduced for two years at our operations, and we see no indication of any impending leap to the previous levels. Greenhouse operations throughout the Northwest have had to respond to this change, and the response has been varied. One operation has been almost totally mothballed; another is planning to consolidate two facilities into one; another is operating at less than 40 percent capacity and is looking to move and build a smaller, more efficient operation. Another operation has diversified and is growing vegetables in some of their greenhouses. It has been a time to prioritize and to reevaluate the value and role of the container program after little more than a decade since its birth. Although some operations have gone by the wayside, the containerized seedling has retained a place in the regeneration effort.

It is obvious that the conditions under which we work in the Pacific Northwest differ significantly from the conditions in the intermountain states, especially the region of the Southwest. I hope that by sharing what we are doing in the Northwest, you might get an idea or two that you can apply at your operations.

GREENHOUSES

The average production facility in the Northwest produces from two to four million seedlings per year, although two facilities produce over eight million per year. Private timber companies own and operate the largest container complexes for their own forest regeneration needs. They also compete for public regeneration contracts. The greenhouse layouts and designs differ based on the state-of-the-art at the time the greenhouses were built. The most popular greenhouse design at this time calls for a fiberglass roof with roll up sidewalls. Common regimes call for heating the greenhouse to 20 C., through May and minimal heating from October through January. Passive cooling through roof vents or active cooling with exhaust fans and evaporative coolers occurs during the hotter hours of June through September.

Therefore, the structure must facilitate both heating and cooling to provide proper growing conditions throughout the year.

ENERGY

Fuel represents up to 15 percent of the cost of our seedlings. Several operations have made significant reductions in their fuel bills by sowing later and by switching from diesel oil to natural gas. Natural gas is the most popular fuel source in the Northwest because of large supplies from Canada. Solar collection may be used more in the future, but the cost to collect and use the limited solar radiation we receive does not compete with gas at this time. A recent greenhouse energy conservation technique is being used by The Bureau of Land Management at Colton, Oregon. The BLM uses infra-red heating in one of their two greenhouses. They report a 30 percent energy savings over their forced-air system. They also believe that the quality of their stock has not diminished.

BENCHES AND CONTAINER TYPES

Bench layouts vary from broad growing troughs, wooden 2" X 4" saw horses, iron flat bars, aluminum T-bars, and aisle eliminating bench tops. The most popular container type is the Styroblock in either the 2A or the 4A size. Commonly seedlings grown in a 2A are transplanted to become plug-1's, and 4A's, are shipped directly to the forest. Other containers have been used such a Leech tubes for genetic stock or Spencer-Lemaire books for <u>Thuja</u>, but the most common container type is the Styroblock.

SOWING AND FERTILIZING

Most of us sow with some type of vacuum sower which picks up one seed per hole from a tray of seed. The seed then falls into the cell when the vacuum is broken. It is most common to multiple sow to ensure a germinant in each cell and then to thin. Soluble fertilizers are mixed according to each grower's preference and injected into the watering system. Fertilizer regimes vary according to species, time of year, and nutrient status as indicated by foliar and soil analysis. Most growers contract their soil and foliar analysis with a private consultant. As is common with many plants, the growth curve of most conifer species that we grow is a sigmoid curve. Growth starts slowly, gradually increases in rate, and finally tapers off in the fall. To produce a quality seedling, it is necessary to find the balance between overfeeding, which produces

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succulent, top heavy seedlings and underfeeding which produces a stunted, starved seedling.

PLUG-1's

If sown in a bareroot seedbed, many of our seedlings such as Abies, Tsuga, and Thuja do not grow quickly the first few years. Commonly we grow these seedlings for one year in the greenhouse and then transplant them at the nursery. These seedlings may be transplanted either in the summer (August, in our area) or in the spring. We call these seedlings Plug-1's. In the nursery transplant bed, they can develop into large enough seedlings to withstand deer and elk browsing or vegetative competition. The shoot of a Plug-1 Tsuga is similar to a 2-1 Tsuga, but the roots of a Plug-1 are mop-like which can more easily support the shoot. The hemlock transplant bed does not have to be shaded or misted as the seed bed requires, and each crop uses valuable nursery bed space for only one year rather than three.

PLUG CULTURE

Back at the greenhouse, seedlings destined to go directly to the forest are kept unshaded and exposed to broader and broader temperature ranges. If you keep temperatures and fertility levels high, you produce a large, succulent shoot at the expense of an adequate root system and caliper. Seedlings, grown in this way, leave the greenhouse unprepared for the vigors of the forest and are commonly frozen back, desiccated or pushed to the ground by the first snow. Our goal is to produce a seedling with a large caliper and good buds, tall enough to compete with surrounding vegetation and with enough roots to support the shoot.

Techniques for inducing budset vary by species. It is common for Pseudotsuga to be leeched, moisture stressed, and then fed a low nitrogen, high phosphorus and potassium fertilizer in September to form large, mature buds for winter planting. However, Tsuga appears to respond best to full light exposure in July and a balanced fertilizer each time the seedling requires moisture. Shading has become less and less popular among Northwest growers. Although many of our trees will grow well under shade, when these seedlings are removed from a shaded house and planted in a nursery or clear-cut reforestation site, the seedlings drop their foliage and must struggle to break bud and begin growing. To avoid this we attempt to grow the seedlings without shade.

SEEDLING STORAGE

We have all struggled with the problem of holding seedlings at lower elevations for late planting at higher elevations. All too often the seedlings break bud in the shelterhouse before the planting site is ready or accessible. Moving these succulent seedlings in the spring from a warm, protected nursery to some cold, harsh site is a frustrating experience for both the nurseryman and the forester. Growers in the Northwest have several different approaches to the problem of seedling storage and I'll share several of these approaches with you.

The Washington State Department of Natural Resources moves their seedlings out of the greenhouse into shelterhouses in June. Here they remain until packaged for field planting which traditionally begins the first week of January. At our location, we feel that this is the time when the seedlings are fully dormant. The seedlings are sprayed thoroughly with a foliar fungicide to reduce damage from storage molds and one week later the seedlings are packaged and stored at 2 °C in poly-lined boxes. The seedlings are kept at this temperature during transport and until the day of planting. All seedlings stored this way should be planted by June. Seedlings to be spring transplanted in the nursery as plug-1's may be stored in this way or kept in the shelterhouse. Container stock is transplanted in mid-March, and plug transplanting is completed by early April, two weeks before bud burst of Pseudotsuga in our area. Seedlings are therefore stored above freezing for 1 to 20 weeks. Storage molds have not been a major problem in our program although we lose a few trees each year. Many nurseries use this method of cooler storage for coastal and low elevation seedlings.

The Weyerhaeuser Company freezes most of their high elevation container stock at 1 to 2 °C. The seedlings are packaged in January and February after having received 400 to 600 hours of exposure to temperatures below 4 °C. Thawing takes from one to two weeks in a shaded warehouse at 4 to 15 °C, before the seedlings are shipped to the planting site. Seedlings are planted shortly after thawing. For more information, contact Steve Hee at Weyerhaeuser Regeneration Center in Rochester, Washington.

The Industrial Forestry Association is a group of timber companies who share a nursery system for the reforestation of their individual lands. IFA does freezer-store container seedlings on request according to vulnerability criteria. There are three vulnerability criteria: (1) coastal seed sources, (2) seedlots which have had a history of winter damage in the nursery and (3) seedlots that are likely to suffer significantly from storage molds. Late in the fall, frost hardiness testing is begun. The lethal temperature for 50 percent LT is established by means of controlled freezing tests. If the seedlings have achieved a set LT, they are considered liftable and storable. Seedlings may be stored frozen for six months. Large quantities may be thawed en masse at 4 °C, but this takes up to six weeks. Small quantities may be thawed in a matter of days at 15 °C. Pseudotsuga, Picea and Abies do not appear to have any problem with this treatment although Tsuga roots are sometimes damaged. For more information, contact Sally Johnson at the IFA

Nursery in Toledo, Washington.

The British Columbia Forest Service also freezer stores many of their seedlings, especially interior seedlots and seedlots that they suspect will suffer significantly from disease problems in storage. When possible, they also make frost hardiness tests. This has indicated to them that, at their interior, harsh environment nurseries, they can begin storing in October but must wait until mid-December at their coastal nurseries. They report successful storage of interior _Picea_, _Pinus_, and _Abies_ at -2 °C. Other seedlings can also be freezer stored but _Tsuga_ appears to be the most sensitive. In trials at the nursery, the roots of seedlings frozen six months do not elongate for 20 days after planting. Bud burst does not occur until 28 days after planting. Their freezer storage length may vary from two to eight months and they are doing research into the sugar and starch balance in six month freezer stored seedlings. For more information, contact Jim Sweeton at the Surrey Nursery in Surrey, British Columbia.

As you can see, both cooler and freezer storage are an important part of our regeneration programs. However, we have not yet worked out a uniform program. I hope that you'll join us in developing this technology.

CONTAINER REUSE

After extracting the seedlings from the containers, the containers are washed and refilled for use in the next sowing. Blocks can be reused many times.

THE FUTURE

During this time of economic stress in the regeneration business, it is significant to note that the value of the containerized seedling has withstood cost/benefit analysis. As the demand for seedlings increases and funds become available, I expect to see more improvements in the containerized program. I look for improvement first in the fertilizer regimes. I anticipate that we will find that each species has a different optimum fertilizer, light, and temperature regime. In fact, I expect to find differences within species native to different climatic zones. Through meetings like these, we can share information but we must continue to try new ideas and document them. Also, we must support, encourage, and participate in research directed at unlocking this information. We must work systematically at producing a quality plant at affordable prices which, not only survives, but flourishes when it is placed in its final growing site.

In: Murphy, Patrick M., compiler. The challenge of producing native plants for the Intermountain area: proceedings: Intermountain Nurseryman's Association 1983 conference; 1983 August 8-11; Las Vegas, NV. General Technical Report INT-168. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 96 p.

THE NURSERY TECHNOLOGY COOPERATIVE:

A COORDINATED EFFORT TO IMPROVE SEEDLING QUALITY

Mary L. Duryea and Steven K. Omi

ABSTRACT: The Nursery Technology Cooperative (NTC) was established July 1, 1982 to improve the productivity of the Pacific Northwest's forest tree nursery industry. The NTC and the two other cooperatives (tree improvement and vegetation management) in the Department of Forest Science are aimed at helping to solve reforestation problems beginning with seed and ending with a free-to-grow forest stand. Membership categories in the NTC include (1) nurseries, (2) seedling users, and (3) specialist organizations. Problem areas for Cooperative study are identified and prioritized by Cooperative members. Our first study, investigating the effects of top pruning on seedling morphology and field growth and survival, has been installed at six nurseries. Planning is in progress for a long-term Cooperative study examining the effects of selected herbicides on weeds and seedlings. Other activities in the Cooperative include (1) a nursery pathology research project, (2) a tissue culture/vegetative propagation project, (3) continuing education (production of a nursery manual), (4) technical assistance (compilation of lists of specialists available to help members), (5) information gathering (collection of state-of-the-art information on compaction, tilth, and drainage), and (6) a seedling evaluation program.

INTRODUCTION

Origin Of The Nursery Technology Cooperative

Because of the importance of the forest nursery industry, a task force was appointed by the Oregon State Forester and the Dean of the School of Forestry, Oregon State University (OSU), to study and report on the status of forest nursery management technology in the Pacific Northwest. The task force found that the forest nursery industry wanted more research and educational assistance, and proposed that a Nursery Technology Center be established at OSU to address these needs. The Nursery Technology Cooperative (NTC) was officially established July 1, 1982.

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Steven K. Omi is Research Assistant, Nursery Technology Cooperative, Department of Forest Science, Oregon State University, Corvallis.

Objective

The objective of the Cooperative is to improve the productivity of the Pacific Northwest's forest tree nursery industry through an integrated program of coordinated studies, information sharing, and technical assistance.

Examples of specific needs to be met through cooperative action are:

1. Better nursery-specific cultural prescriptions for the improvement of seedling physiological quality.

2. Improved soil management guidelines for the maintenance of long-term nursery productivity.

3. More effective coordination of nursery and outplanting techniques.

4. Better information sharing among nurseries, and between nurseries and related groups such as reforestation foresters and researchers.

Why Cooperatives?

The three cooperatives in the Department of Forest Science at OSU have been established to help solve reforestation problems beginning with seed and ending with a free-to-grow forest stand. The Tree Improvement Research Cooperative, headed by Thomas Adams, coordinates genetics and breeding research on Pacific Northwest tree species to enhance tree improvement efforts in the region. The Nursery Technology Cooperative, by helping to increase nursery productivity, will aid in the better utilization of improved seed and the matching of high quality seedlings to planting sites. At the outplanting stage the CRAFTS Cooperative, headed by Steven Radosevich, helps to coordinate research on methods of controlling competing vegetation in commercial forests of the Pacific Northwest.

Cooperatives enable us to:

1. Define and study useful problems.

2. Reduce fixed costs per cooperator to study these problems.

3. Investigate treatment x site interactions.

4. Rapidly use results.

5. More effectively share information by using OSU as a clearinghouse.

Organization

Fifteen members from state and federal agencies and industry participated in the Cooperative in its first year (Appendix 1). A Technical Committee and a Policy Committee assist the NTC leadership. The Policy Committee advises the Cooperative Leader on decisions concerning program strategy, size, and support. The Technical Committee helps to identify and prioritize problems, and assists in planning, installing, and measuring Cooperative studies. Together, the Policy and Technical Committees guide the activities of the Cooperative, insuring that efforts are focused on real problems.

The NTC membership categories (and annual membership fees) are: (1) nurseries (large--$6,000 and small--$3,000), (2) seedling users (full--$4,000 and monitoring--$2,000), and (3) specialist organizations ($2,000 to $4,000). All members (except for the seedling user monitoring members) have representation on the Technical and Policy Committees, and are directly involved in nursery and outplanting studies. Seedling user monitoring members receive study results only, and do not participate in guidance.

Figure 1.--Top pruning with a rotary mower at the D.L. Phipps Forest Nursery (Oregon State Department of Forestry).

ACTIVITIES

Cooperative Studies

Problem areas for study are identified and prioritized by Cooperative members. Top pruning and weed control will be investigated in our first short-term and long-term studies, respectively.

Top pruning.--This study was installed in May, 1983, to examine the effects of top pruning on 2+0 Douglas-fir seedling morphology, survival, and growth. Top pruning is a common practice in western nurseries (fig. 1); however, there is little available information about the effects of top pruning. Treatments for the experiment include two different pruning heights, two different times of application, and one multiple pruning. The entire experiment, with one seed zone was replicated at three nurseries; a smaller version, involving fewer treatments, was included so that more seed sources could be tested. In total, six nurseries (fig. 2) and nine seed zones are involved in the study. Test seedlings from each seed zone will be planted on sites located within their respective zones. In addition, a common garden study, including seedlings from all seed zones, will be established at the OSU McDonald Forest. The growth and survival of outplanted seedlings will be monitored for up to three years.

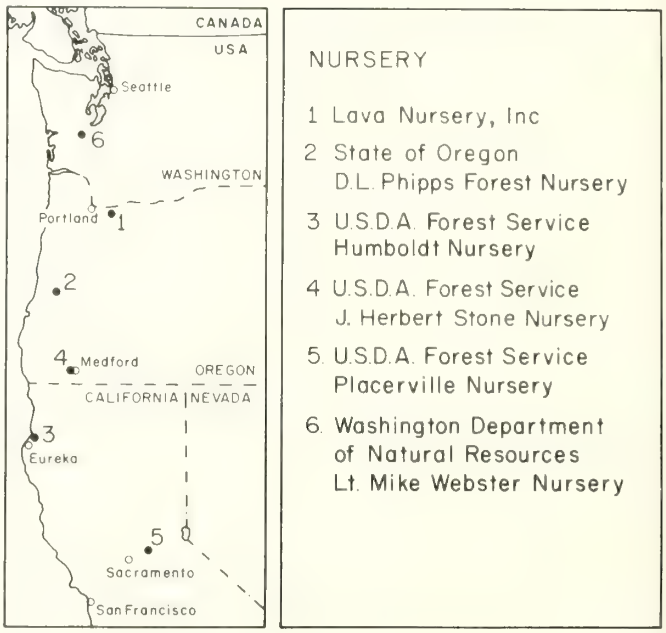

Figure 2.--Map showing the location of the six nurseries where the top pruning study has been installed.

Weed control.--Planning is in progress for a long-term Cooperative study that will examine the effect of selected herbicides on weeds and seedlings. Presently used methods of weed control (e.g., handweeding, fumigation) are costly and may be detrimental to tree seedlings and soil microorganisms. The objective of this study will be to screen new and currently available herbicides for their effectiveness in controlling weeds without injuring conifer seedlings. Additionally, we want to determine the residual effect of herbicides on weeds and crop species.

Other Cooperative Projects

Two other OSU projects are connected with the NTC: the Nursery Pathology Research Project, headed by Everett Hansen, and the Tissue Culture/Vegetative Propagation Project, headed by Joe Zaerr. Both projects are meeting Cooperative objectives, although both are funded by sources other than Cooperative annual fees.

Nursery pathology research project.--The broad goal is to provide the biological information necessary to predict and prevent disease outbreaks in nurseries. The initial focus of the project will be on the various top blight diseases that have caused substantial loss in recent years. In preliminary work, systematic isolations have been made from blighted seedlings at a Pacific Northwest nursery to identify suspected pathogens. These isolates, plus those from three other participating nurseries, will be tested for pathogenicity. Timing, environmental, and predisposing factors that influence infection will be determined for the identified pathogens.

Tissue culture/vegetative propagation project.--The objective of this project is to develop techniques for producing large quantities of superior forest trees by means of tissue culture. The approach has been to measure growth hormones in cultures and to determine which hormones produce the desired results. Work to date has resulted in the development of techniques to isolate and detect plant hormones in extremely small quantities. These techniques have been used to measure auxin in callus cultures and in cultured buds. Cytokinins, another class of growth hormones, were measured in suspension cultures of Douglas-fir. The results of these studies indicate that the growth hormone requirements for embryogenesis (producing whole plants from cell cultures) probably are very specific, and that the growth hormones that have been used in previous attempts to produce embryogenesis are probably not the ones that should be used.

Future work will include a broadening of the objective to include other methods of propagation, such as the rooting of cuttings, and the problems associated with those techniques.

Continuing Education

The Forest Nursery Manual: Production of Bareroot Seedlings includes 30 chapters covering specific topics such as nursery site selection, fertility management, and seedling storage (fig. 3). A comprehensive survey of Northwest nurseries provided the authors of each chapter with information on current cultural practices. In addition, each chapter contains a state-of-the-art review of nursery research. A workshop held at OSU in October, 1982 previewed the manual for over 250 people. The manual will be published this summer, 1983. Both the Manual and the workshop have been co-sponsored with the USDA Forest Service, State and Private Forestry, Region 6.

FOREST NURSERY MANUAL:

PRODUCTION OF BAREROOT SEEDLINGS

Mary Duryea and Tom Landis, Editors

I. Development of the Nursery Manual: a synthesis of current practices and research

II. Developing a Forest Tree Nursery

III. Starting the Bareroot Seedling

IV. Managing the Soil and Water

V. Culturing the Bareroot Seedling

VI. Harvesting and Planting the Bareroot Seedling

VII. Selected Topics in Nursery Management

VIII. Upgrading Nursery Practices

Figure 3.--Major Sections in the 30-chapter Forest Nursery Manual.

Seedling Physiology and Reforestation Success will be the title of the Physiology Working Group Technical Session to be held at the Society of American Foresters (SAF) National Convention in Portland this October, 1983. The one-day session will include both overview and specific research reports concerning the effects of seedling physiology on reforestation success, with major emphasis on stock quality and planting site manipulation. The proceedings of the session will be published in 1984.

Technical Assistance

As part of our commitment to improve information flow and technical assistance, we are compiling lists of specialists who would like to help nurseries and reforestation people. Questionnaires (fig. 4) have already been sent to insect/disease, soils, weed control, and irrigation specialists, seedling physiologists, and silviculturists. A very positive response has been received--many have expressed a strong desire to be involved in workshops, Cooperative studies, and problem solving. Other specialists who will be contacted include agricultural and industrial engineers, seed physiologists, crop scientists, and horticulturists. The list of specialists for insect and disease, soil, and irrigation problems have been sent to Cooperative members.

Members are encouraged to contact specialists directly from these lists when the need for technical assistance arises. However, they may also receive help from the NTC staff in making contacts with specialists by stating their specific problem on a Technical Assistance Request Form. The NTC staff responds immediately to these requests by providing ways to approach the stated problem.

Information Gathering

Cooperative members have expressed a need for being informed of the state-of-the-art knowledge on several topics. Soil management (tilth/compaction/drainage) has been selected as the problem area in which information gathering is currently needed. The NTC staff is presently reviewing the literature and collecting relevant material. A summary, available to all members, will follow.

Seedling Evaluation Program

The purpose of the NTC Seedling Evaluation Program is to improve techniques for assessing seedling quality. As part of this program, the NTC provides a seedling vigor evaluation (or stress testing) service. More than 250 seedling lots were evaluated this year on a fee basis. This procedure is designed to identify poor quality lots by monitoring the growth and survival of potted seedlings placed in a growth room after exposure to hot-dry conditions. Although this procedure has been very useful, work continues to refine the test. A study is being conducted to determine the effectiveness of the current procedure in predicting field survival under uniform planting conditions. We are also examining the relationship between the vigor evaluation results and standard measurements of root growth capacity. This investigation will indicate whether these two assessment procedures are consistent in predicting field survival or, perhaps, are complementary and could be used together to improve prediction accuracy. The study began in March, 1983.

SPECIALIST QUESTIONNAIRE

Nursery Technology Cooperative

Name ______________ Affiliation ______________

Address ________
____
____

Phone Number ____

IN THIS QUESTIONNAIRE WE ARE SEEKING INDICATIONS OF INTEREST AND NOT NECESSARILY A FIRM COMMITMENT TO PARTICIPATE.

1. a. Would you be interested in being involved in the Nursery Technology Cooperative? (check yes or no)

   Yes ______ No ______

   b. In what cooperative efforts might you be willing to participate? (check yes or no for each starred (*) area below)

	Yes	No
(1) *Workshop teaching?		
(2) Studies:		
*Review of study plans?		
*Active involvement in experiments?		
(3) *Team problem solving and providing technical assistance through the Cooperative?		
(4) *Individual direct consulting?		
(5) *Others? (please specify below)		

Figure 4.--Page one of the questionnaire being sent to specialists in the West.

Another recently completed study in the NTC Seedling Evaluation Program was aimed at developing a specific procedure for detecting damage to seedlings which have been unintentionally frozen during cold storage. In this study, we found that a pressure chamber could be effectively used to identify this type of injury. Results indicate that the change in plant mois-

ture stress (PMS) of potted seedlings during the first week after freezing can generally predict whether or not they will survive. The PMS of damaged seedlings tends to increase much more rapidly than that of non-injured seedlings. A more complete description of this study is reported by Douglas McCreary in this proceedings.

LOOKING AHEAD

In its second year the NTC staff is (1) coordinating the NTC studies (top pruning, weed control), (2) providing continuing education programs (Physiology Workshop at the SAF National Convention, publication of the Forest Nursery Manual), (3) updating the Seedling Evaluation Program, (4) supporting other projects within the NTC (Nursery Pathology, Tissue Culture/Vegetative Propagation), (5) providing technical assistance (compilation of specialists lists), and (6) gathering information on soil management, and, given continued Technical Committee interest, a soil management study plan will be prepared.

APPENDIX I

Members of the Nursery Technology Cooperative.

Nurseries:

- Lava Nursery, Inc.
- Oregon State Department of Forestry, D. L. Phipps Forest Nursery
- USDA Forest Service, Rogue River National Forest, J. Herbert Stone Nursery
- Washington State Department of Natural Resources, Lt. Mike Webster Nursery
- Weyerhaeuser Company

Seedling Users:

- BLM--Coos Bay District
- BLM--Eugene District
- BLM--Medford District
- BLM--Oregon State Office
- BLM--Roseburg District
- BLM--Salem District
- USDA Forest Service, Umpqua National Forest

Specialist Organizations:

- USDA Forest Service, Pacific Northwest Forest and Range Experiment Station
- USDA Forest Service, Pacific Southwest Forest and Range Experiment Station
- USDA Forest Service, State and Private Forestry, Region 6

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USING A PRESSURE CHAMBER TO DETECT DAMAGE TO

SEEDLINGS ACCIDENTALLY FROZEN DURING COLD STORAGE

Douglas D. McCreary

ABSTRACT: During cold storage, seedlings are sometimes accidentally frozen. A study to determine if a pressure-chamber device could be used to detect the extent of this type of injury indicated that the change in plant moisture stress of potted seedlings during the first week after freezing is a reliable measure for predicting seedling survival.

INTRODUCTION

Storage of bareroot seedlings is often a necessary step in the reforestation of conifers, as labor, geographic, and climatic constraints make it virtually impossible to plant seedlings immediately after they are lifted. It is well established that the temperature during storage can greatly affect seedling quality (Hocking and Nyland 1971). Currently, most conifer seedlings are stored between 0° and 3°C because cold temperatures reduce respiration and inhibit the development of harmful molds. But, despite improvements in the overall quality of refrigeration facilities, occasional equipment malfunctions result in seedlings being exposed to subfreezing temperatures. Such exposure can be especially injurious to root systems, which are more sensitive to freezing than shoots. Unfortunately we know little about the tolerance of roots to this type of injury, nor is there a simple and effective method of identifying its extent. When such a storage problem is discovered and it must be decided whether seedlings should be discarded or planted, there is little on which to base a decision. Consequently, in December 1982, as part of the Nursery Technology Cooperative at Oregon State University, we initiated a study to determine if a pressure-chamber device could be effectively used to identify seedlings that were severely damaged by accidental freezing during storage.

METHODS

One hundred, 2-year-old Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) seedlings from a common seed source were randomly divided into 10 equal groups for 10 temperature treatments. Each group was placed in a sealed plastic bag in a freezing chamber programmed to remain 1 hour at +1°C. The temperature was then lowered at the rate of 2°C per hour. We removed the first bag at -3°C and continued to remove one bag every half hour at each drop of 1°C until the temperature was -12°C. Immediately after removal from the freezing chamber, each bag was placed in a cold room (+1°C) and left overnight to thaw gradually.

The day after thawing, all seedlings were tagged with their freezing-treatment number and planted randomly in pots, one seedling from each treatment in each pot.

The following day, a small lateral branch from each seedling was removed and placed in a pressure chamber to determine its plant moisture stress (PMS). This procedure was repeated on the fourth and sixth days after potting. PMS was recorded as a positive number, so that an increase indicated greater water deficit within the seedlings. The night before each PMS determination, all pots were watered to field capacity to ensure similar soil moisture conditions for each pot on each evaluation date.

The seedlings were maintained for 2 months in a growth room under a 16-hour photoperiod and constant 22°C temperature. During this time, the pots were watered regularly and soil moisture remained fairly high. At the end of this period, we recorded the percentage of dead seedlings from each of the 10 freezing treatments and calculated the average PMS per treatment for each assessment date. For each treatment, we calculated the average absolute increase and average percentage increase in PMS between the first and fourth and the first and sixth days after planting.

We then determined if there was a significant relationship between freezing temperature and PMS on each date. Next we calculated correlation coefficients for the relationships between mortality and absolute and percentage changes in PMS over all treatments. Finally, we determined the average PMS for seedlings that lived and those that died and tested for significant differences. All reported differences were significant at $P = 0.01$ unless otherwise stated.

RESULTS

Twenty of the original 100 seedlings died during the 2-month assessment period. Figure 1 shows mortality percentages for each freezing treatment. Sixteen of the dead seedlings were from the two lowest temperatures, which indicates that among seedlings of the seed source used,

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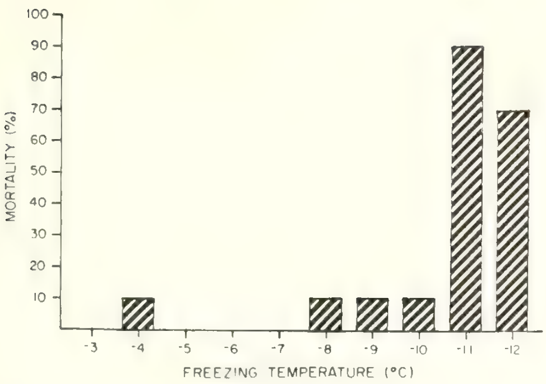

Figure 1.--Final mortality of seedlings, by freezing treatment.

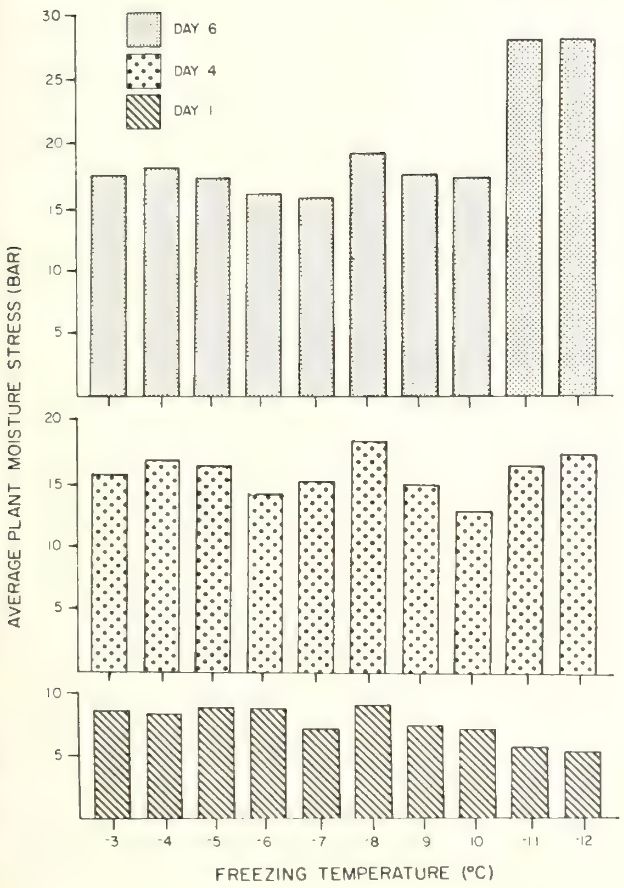

Figure 2.--Average plant moisture stress of seedlings, by treatment and day of evaluation.

the threshold temperature for lethal damage (-11°C) was quite uniform. Figure 2 shows

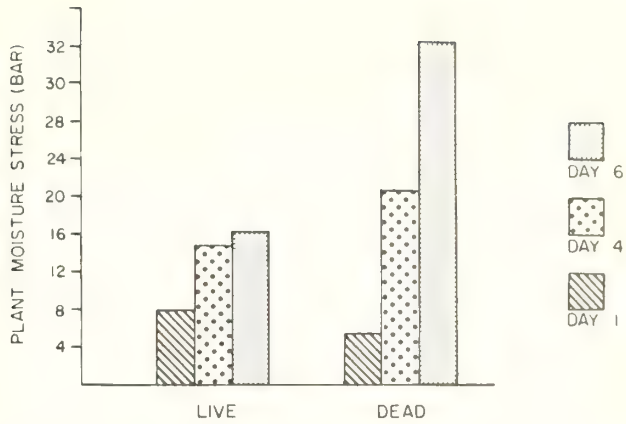

Figure 3.--Average plant moisture stress of surviving and dead seedlings.

average PMS by treatment for each assessment date. There are three interesting things to note: first, that average PMS for all treatments increased over time; second, that first-day PMS tended to be lower in the colder treatments (freezing temperature and PMS were significantly and positively correlated); and third, that this initial trend dramatically reversed during the following 5 days. Seedlings from the two coldest treatments had the highest average PMS values on the sixth day after planting, and freezing temperature and PMS were significantly ($P = 0.05$) and negatively correlated.

The relationships between lethal freezing injury and PMS (fig. 3) show that seedlings that died had significantly lower initial PMS values that then rose precipitously. Seedlings that lived had higher initial PMS values that increased gradually between the first and fourth days and then remained relatively unchanged. PMS on the sixth day, and the percentage difference between the first and sixth days, were significantly higher for those seedlings that eventually died.

As might be expected from this discussion, the percentage of dead seedlings from a given freezing treatment was closely correlated with the absolute and percentage increase in PMS for that treatment. There was a strong correlation between mortality and both absolute and percentage increases in PMS for both measurement intervals (days 1 to 4, days 1 to 6). Significant correlation coefficents were:

Percentage mortality x absolute increase in PMS

Days 1 to 4	$r = 0.80$
Days 1 to 6	$r = 0.98$

Percentage mortality x percentage increase in PMS

Days 1 to 4	$r = 0.85$
Days 1 to 6	$r = 0.96$

Although all correlations were significant, the larger coefficents for the longer time intervals indicate that predictions of mortality from PMS

change are more reliable after 5 days than after 3 days.

CONCLUSIONS

Our initial hypothesis was that accidental freezing during cold storage can injure root systems, so that seedlings cannot take up water and maintain an adequate moisture status once they are planted. The data are consistent with this view. Seedlings killed by the freezing treatments became more stressed over time than seedlings that lived, although they initially had lower PMS. An initial reduction, also found by Bixby and Brown (1974) and Timmis (1976), is apparently caused by internal rupturing of cells and release of water into the xylem. Over time, the transpirational demand probably depletes the available water in the seedlings, and PMS rises rapidly as the water is not replenished by the injured root system.

Because we found considerable variability in the initial PMS values of seedlings receiving the same freezing treatment, and because the change in PMS was so closely correlated with lethal injury, we believe that the procedure outlined--measuring seedlings once soon after planting and once 5 days later--is a more reliable technique for predicting injury than a single PMS measurement. The exact magnitude of change in PMS that indicates severe freezing damage, however, is not clear. In this study, a 4-fold increase between the first and sixth days reliably indicated seedling mortality; those with less than a 4-fold increase in PMS lived. The 4-fold separation value predicted the final survival status of 97 percent of the seedlings. In preliminary results from another trial, however, a 3-fold increase during the first week after planting indicated mortality. In this second trial, there was little or no change in the PMS values over time for most surviving seedlings, in contrast to the rough doubling of PMS between the first and sixth days for surviving seedlings in the study reported here.

Although some calibration must be done to perfect the technique, the data clearly suggest that a pressure chamber can be a very useful tool in identifying seedling injury caused by unintentional freezing during cold storage. The assessment procedure outlined is simple, requiring only a pressure chamber and a small amount of greenhouse or growth-room space, and it can be completed within a week after the suspected injury occurs.

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ASEXUAL VS. SEXUAL PROPAGATION OF QUAKING ASPEN

Robert B. Campbell, Jr.

ABSTRACT: Quaking aspen (Populus tremuloides Michx.) regenerates almost exclusively by root suckers in the western United States, even though female clones produce abundant viable seed. During the past decade, interest in propagating aspen for use as an ornamental and for revegetation of forest land has increased. To satisfy these diverse needs for aspen planting stock, nurserymen have a choice between sexual and asexual propagation. Criteria for clone selection, suggestions for root and seed collection and storage, propagation techniques, and the advantages of both sexual and asexual propagation are discussed.

INTRODUCTION

Quaking aspen (Populus tremuloides Michx.) has the widest distribution of any native tree species in North America (Fowells 1965). This significant fact suggests that quaking aspen can grow under a vast range of environmental conditions. Thus, if aspen could be successfully propagated, it could be used widely as an ornamental and for reforestation and land reclamation. In the western United States, this important species relies almost entirely upon vegetative regeneration from root suckers. Female clones, however, produce many viable seeds.

Interest in propagating quaking aspen for use as an ornamental and for reforestation surged during the past decade. Vegetative propagation techniques have been developed (Schier 1978b) and have specific advantages. However, seed propagation is less labor intensive and is used by some nurseries to produce large quantities of planting stock.

I will present various factors that nurserymen should consider before selecting between sexual and asexual methods of propagating aspen.

ASEXUAL PROPAGATION

Quaking aspen clones have numerous long, lateral roots in the top 6 inches of the soil profile. Suckers may arise along these roots and become a younger generation of ramets that are genetically identical to the trees of the parent clone.

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Many amateur and professional landscapers transplant these natural suckers, or wildlings, for ornamental purposes. When the wildlings are dug up, the soil usually falls away exposing the root system. Typically, the transplant's root system consists of only a 12- to 18 inch segment of lateral root from the parent clone. Once transplanted, the wildlings usually grow slowly at first and develop small leaves. Generally they have few, if any, branch roots at the time they are removed from the parent clone, and the existing root system is inadequate; consequently many wildlings do not survive after transplanting (Schier 1982).

A few commercial landscapers report good survival and growth of transplanted aspen when the suckers have well-developed, independent root systems. They are careful to keep the root ball tightly bound, which protects the fragile new roots. Sharp shovels are used to minimize root damage, which can be an infection site for pathogens. It is best to transplant aspen in the dormant stage. Survival can be excellent when aspen 3 to 5 inches diameter at breast height (d.b.h.) and 18 to 20 ft tall are carefully transplanted with a 44-inch tree spade. (Personal communication with Ron McFarland of Landscaper's Service, Steamboat Springs, Colo.)

Another nurseryman substantially improves the survival and vigor of transplanted wildlings as follows: (1) Wildlings are selected from undisturbed clones where the regeneration varies in size and age. (Failure apparently is common when wildlings come from clones with a history of disturbance as characterized by many suckers of the same age.) (2) When trees 3 to 5 inches d.b.h. are transplanted, the trees are first wiggled and only those trees that are firmly rooted in all four directions are selected. (3) After transplanting, the aspen are given three applications of a complete foliar fertilizer and one hydraulic injection of the fertilizer into the root system. (4) The trees are sprayed with Benomyl (a systemic fungicide) to reduce the incidence of fungal pathogens common to aspen. (Personal communication with Jerry Morris of Rocky Mountain Tree Experts, Lakewood, Colo.)

Methods have been developed to artificially propagate aspen vegetatively (Schier 1978b). Though labor intensive, these methods offer a way to produce rooted aspen suckers capable of vigorous growth. I want to dispel the myth that vegetatively propagated aspen inherently have slow growth. Aspen trees propagated vegetatively 14 years ago at Logan, Utah, are now 32 ft tall.

Clone Selection

In 1976, aspen suckers were propagated vegetatively from 10 healthy and 10 deteriorating clones in Logan Canyon. Schier and Campbell (1980) describe the site and suckering characteristics for these 20 clones. The two groups of clones differed appreciably with respect to aspen density, basal area, and mortality.

The rooted sucker cuttings were planted in tubes, 2.5 inches in diameter by 10 inches long, filled with peat moss:vermiculite (1:1) and placed in the greenhouse. The next spring the suckers were transplanted to peat moss:sand (3:2) in 1 gal pots and moved to the lathhouse. Under the direction of Dr. George A. Schier, the young trees were transplanted during spring 1978 to a common garden at the Green Canyon Nursery 3 miles northeast of Utah State University.

A total of 439 aspen were planted randomly in 15 rows of up to 30 individuals per row with a 6.6-ft spacing. Soil amendments and fertilizers were not used at the nursery. Rainbird sprinklers provided regular but moderate irrigation. After 2 years at the nursery, the trees had substantial variation in height growth. In an attempt to standardize subsequent vegetative growth, all stems were cut off at ground level in the spring of 1980. Thus all new suckers started from established root systems. As new suckers arose, a dominant sucker was selected; all other remaining and subsequent suckers were cut off.

The new suckers are now in their fourth growing season, and some trees are over 12 ft tall. Data recorded include: height growth for each year, the number of lateral branches, the length of the longest three laterals, and stem form. Preliminary results indicate that substantial variation in these morphological traits occurs between clones. Also, clonal variation is obvious for the time of leaf flush, leaf size and shape, and the angle of branching between the main stem and lateral branches. This common-garden planting illustrates well the genetic control of these characteristics in aspen.

The survival rate in the common garden is an impressive 99 percent. Of the 439 aspen planted, only three died; two others were stolen. Although a few trees have poor growth, at least 95 percent have acceptable growth.

Many factors should be considered when selecting a clone for asexual propagation. Do the trees in the clone have a desired shape and appearance? Is the soil type desirable for root collection? Are there abundant (or sufficient) lateral roots near the soil surface? Will the roots collected have a high capacity to sucker, and will the sucker cuttings develop roots? (Preliminary trials are suggested to determine the clone's suckering and rooting capabilities.) These questions relate to specific factors that vary greatly among clones in nature.

Tree height may be a misleading guide for acceptance or rejection of a prospective clone. Environmental conditions, particularly those related to available moisture, strongly influence height growth. One would expect trees vegetatively propagated from a clone with tall trees to grow reasonably tall; however, I have seen suckers propagated from clones with short trees on a poor site grow unusually fast and tall in a better environment.

Harniss and Nelson (in press) indicate that aspen clones vary in susceptibility to *Marssonina*, a fungal leaf blight. They surveyed about 1,000 acres of aspen in northern Utah during a recent epidemic year for *Marssonina*. Resistant or lightly infected aspen trees occupied only 18 percent of the total area. They suggest that the best control of this leaf blight, particularly for ornamental and revegetation purposes, would be to select for highly resistant clones.

Numerous desirable traits of specific aspen clones can be perpetuated by vegetative propagation. Barnes (1966) suggests that the following characteristics are generally uniform among the ramets of the same clone: leaf size, shape, and color (both spring and fall); phenology; stem form and branching habit (for example, excurrent growth or wide spreading crown and degree of self-pruning); sex; bark color and texture; and tendency for disease and insect attack. These traits may be important to consider when a clone is selected.

Root Collection and Storage

Schier (1978b) explains in detail the root collection process. He mentions specific advantages for using a spade, an anvil-type pruner, and a moist cloth bag for collecting lateral roots that range from 0.4 to 1.0 inch in diameter.

The season of root collection can significantly alter the number of suckers produced. During the spring flush and early shoot growth, the roots of aspen clones have high levels of auxin, which reduces sucker formation (Schier 1973). Schier (1978b) explains that roots collected during the clone's dormant stage (early spring, later summer, or fall) typically yield more suckers than those collected during active growth. He notes that early spring collections are easier to make and result in less root damage because the soil is still moist.

Perala (1978) and Schier (1978a) report that the number of aspen suckers produced is not related to the length of the root cuttings. Because the length is not a critical factor, roots can be cut for the convenience of tray size and available space.

Schier and Campbell (1978) suggest that in some situations it may be useful to hold aspen roots in cold storage before planting the roots to begin the suckering process. For example, nurserymen could have the flexibility to collect

roots from clones at different times, hold them in cold storage, and then plant the roots at the same time. In addition, the first growing season for the new suckers could be lengthened if the roots were collected in the fall, stored, and then planted in the greenhouse during late winter. Schier and Campbell (1978) treated root segments with Benomyl, wrapped them in moist paper towels, placed them in plastic bags, and stored them in the dark at 36° F for up to 25 weeks. In most cases the cold storage did not significantly alter the number of suckers produced by the roots. They suggest that roots from most clones can be stored for extended periods of time and still produce suckers suitable for propagation. Even after storing root cuttings from three clones for 12 months in a cold room, I found that some suckers still arose from the roots. When the remaining roots from the same lot were tested next at 18 months, they were rotten and did not sucker.

Propagation Method

Briefly, procedures developed by Schier (1978b) to vegetatively reproduced aspen are: (1) Collect lateral roots from desirable clones. (2) Clean the roots, cut to suitable lengths, treat root segments with Benomyl, and plant them horizontally at a depth of 0.5 inch in trays of vermiculite. (3) Place the trays in a greenhouse, water lightly each day, and allow the root segments to sucker for 6 weeks. (4) Cut the new suckers from the root segments, treat the suckers' bases with indolebutyric acid (IBA), and plant the sucker cuttings in moist vermiculite:perlite (1:1). (5) Put these cuttings on a misting bench for 2 to 3 weeks to root. (6) Transplant the rooted cuttings to containers with peat moss:vermiculite (1:1) and apply a complete fertilizer. Use supplemental light during short days and maintain the temperature between 59° and 77° F. Aspen have winter chilling requirements that are satisfied at 36° to 50° F.

SEXUAL PROPAGATION

Female aspen clones produce highly viable seed in the spring (Fowells 1965; McDonough 1979). Growing aspen from seed is less labor intensive than the asexual methods discussed above. Some nurserymen are growing seedling aspen on a production scale. Native Plants, Inc. presently has in its nursery several hundred thousand aspen seedlings of various sizes, both as bare root stock and in containers (personal communication with Mike Alder, Native Plants, Inc., Salt Lake City, Utah).

I will comment on several items that may be useful to nurserymen who wish to propagate aspen from seed.

Clone Selection

Not all aspen clones bear seeds. Typically, aspen have imperfect flowers arranged in catkins. With few exceptions, all of the catkins produced in a clone will be the same sex. Reports in the literature suggest that the male to female ratio of aspen clones varies in some areas in favor of the male (Fowells 1965, Grant and Mitton 1979). From my general observations, I believe that only 20 to 25 percent of the clones in the West will set seed in any one year. Thus, finding female clones with seed is a major limitation for clone selection.

Before flowering, the winter floral buds usually can be picked apart and carefully observed with a hand lens to determine the sex. The best time to determine the clone's sex is mid- to late spring when the catkins are extended. The male catkins have a cluster of purple anther sacs on each scaly bract. The female catkins have a single, green, top-shaped capsule at each bract. Although catkins disintegrate rapidly after shedding pollen or seed, enough fragments to identify the clone's sex usually will remain on the duff layer throughout most of the summer. Emphasis should be placed on finding female clones with desirable attributes for the proposed use of the new seedlings. Nevertheless, because of genetic recombination the seedlings will not be exactly like the trees in the female clone. The odds for desirable offspring, however, should be better if the female clone has the preferred characteristics.

Seed Collection

Aspen flowering is controlled in part by temperature. Because of this, the same clone may vary up to 3 weeks in date of flowering from year to year. Temperature also affects flowering phenology along elevational gradients, with earliest flowering beginning at the lower elevations. In northern Utah male and female catkins usually begin to emerge in mid- to late April. The male catkins soon elongate and the clusters of purple anther sacs begin to shed pollen. Following pollination, some 4 weeks later as the leaves begin to flush out, the female catkins elongate as the seeds mature and the green capsules swell. One to 2 weeks later the capsules open and shed the seed in a fluff of cottonlike hairs.

Rather than collecting the cottony fluff in the field, use a long pruner to cut branches from trees with female catkins about a week before the seed would ordinarily be shed. The catkins can then be forced in a greenhouse or laboratory.

A method commonly used in Europe for seed harvest from European aspen (*Populus tremula*) will also work for quaking aspen. The cut ends of the catkin-bearing branches are placed in containers filled with water. Water is added as needed and kept at a temperature of 46° to 50° F. High air temperatures (68° to 104° F), low relative humidity, and gentle ventilation quicken the ripening process. The catkins should not be exposed to full sunlight. When the capsules open, a suction device is used to remove the

cotton and seed. The seed will separate from the cotton as the air current passes through a series of three cylinders connected by small tubes. The viable seed accumulates in the first two cylinders (FAO 1979).

Aspen seed need not be removed from the cotton for germination, but cleaned seed is easier to handle. The mature seed is tan, plump, and small; Schreiner (1974) indicates there are about 3 million cleaned seeds per pound.

Seed Viability and Storage

McDonough (1979) stresses that aspen in the West produce ample amounts of nondormant, germinable seed. However, inadequate soil moisture during germination and early seedling growth usually prevents establishment under field conditions. He found germination capacities of 90 to 100 percent at temperatures from 36° to 86° F. Germination began within 8 to 12 h when temperatures were 68° to 95° F. Also, seeds air dried for 2 days at 68° F and then stored in vapor-tight bottles at 28° F for 48 weeks retained 90 percent or better germinability.

McDonough (1979) shows that the depth of planting greatly affects seedling emergence, which decreases significantly if the seed is placed deeper than 0.15 inch below the surface. Greenhouse seedbeds and standard potting soils are suitable for germination and seedling establishment when watered gently.

Poplar seed can be stored for several years with only a slight decline in the germination rate if stored in a cool, closed container with low humidity (FAO 1979). Fowells (1965) explains that good seed crops for aspen occur every 4 to 5 years, with only light seed production in the other years. Nurserymen could collect seed during the years of abundant seed and store it for a few years without appreciable declines in germination potential.

We collected seed in May 1979 from one clone in northern Utah, air dried the seed for 2 days, and then stored it in a sealed plastic envelope at 36° F. Initially the germination rate was 94 percent. I tested the seed lot in April 1982 and observed a 92 percent germination capacity. In April 1983, after 4 years of cold storage, the seeds still had 82 percent germinability.

DISCUSSION

The propagation of aspen from seed requires less equipment, labor, time, and space than intensive vegetative methods of propagation. In addition a large outplanting of seedling stock tends to maximize the genetic variation available in the gene pool. Such variation is a benefit to reforestation and land reclamation because it enhances the adaptability and survival of the total outplanting. These uses normally require large numbers of planting stock that are more feasible to grow from seed.

In contrast, vegetative propagation yields new ramets genetically identical to the parent. Nurserymen can select for the superior clonal traits preferred by their clientele. The future for asexual propagation of aspen is promising with many possibilities for new advances. In fact, tissue culture, another form of vegetative propagation, is currently being used by Native Plants, Inc. to grow tens of thousands of aspen plantlets from a single seedling tree that has superior traits (personal communication with Mike Alder, Native Plants, Inc., Salt Lake City, Utah).

I stress two recommendations that apply to both methods. General wisdom indicates that clones selected for either root or seed collection should be in the same general area and elevation as the anticipated outplanting, whenever possible. Also, aspen respond best when the fertilizers applied contain a full complement of macro- and micronutrients.

Aspen can be readily propagated by either sexual or asexual methods, both of which have unique advantages. Nurserymen are challenged to capitalize on these advantages to produce aspen stock tailored for specific uses.

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EFFECTS OF SOIL AMENDMENTS ON ASPEN SEEDLING PRODUCTION

James T. Fisher and Gregory A. Fancher

ABSTRACT: Quaking aspen (Populus tremuloides Michx.) seedlings were grown in north central New Mexico in a mountain valley nursery soil amended with sulphur and one of four levels of peat moss (0, 1/4, 1/2 and 3/4 peat (v/v). The 1/4 peat treatment is equivalent to 374 m^3/ha. Peat moss improved soil medium physical and chemical properties responsible for improving seedling growth with each addition. Sulphur alone did not produce satifactory seedlings. Peat-amended soil produced plantable seedlings in one growing season at the study site.

INTRODUCTION

The geographical range of quaking aspen (Populus tremuloides Michx.) is enormous in western North America; it spans over 40° latitude. More than 200,00 hectares are occupied in New Mexico, Arizona, and the adjacent San Juan Basin (Jones and Trujillo 1975) where aspen forests provide numerous human benefits and renewable resources.

High on the list of potential benefits is the role aspen can play in redirecting the course of wildfire. In the southern Rockies, aspen has a lower fire potential than conifer types and can provide a critical fuelbreak. Flammability of aspen has been estimated to be less than one half that in adjacent conifers (Fechner and Barrows 1976). This might explain why wildfires spreading from high elevation conifer forests have been observed to die out in aspen. Healthy stands of aspen are regarded by fire managers as relatively fire proof. It follows that maintenance and establishment of aspen are useful fire management practices, particularly in mountain resort areas where ignition is likely and the potential for loss of resource value and life is great.

At present, land managers in the Southwest do not possess a full understanding of the steps necessary to grow aspen seedlings reliably and efficiently, nor of those steps leading to fuelbreak establishment. Through a U.S. Forest Service-Eisenhower Consortium cooperative research project begun in 1981, we are developing or refining greenhouse, nursery, site preparation and weed control practices leading to establishment of aspen. This paper addresses bareroot seedling production.

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Production of aspen seedlings from seed has been largely ignored in the West until recent years. However, large-scale production was achieved more than one decade ago in the Great Lakes region, notably at the Institute of Paper Chemistry (IPC), Appleton, Wisconsin (Benson and Dubey 1972). The methods developed by IPC supplanted conventional nursery practices which generally failed to avoid:

(1) rapid loss of seed viability in the seedbed
(2) washing of the seed
(3) drying of the surface soil during the first two weeks
(4) damping-off during the seedling stage

The specific objective of this study was to apply IPC methods at a northern New Mexico mountain valley nursery site while testing soil amendments potentially useful in reducing soil pH and density. This refinement was believed necessary to avoid seedling disease and nutritional disorders, and to minimize nursery lifting difficulties.

METHODS AND MATERIALS

The study was conducted at Mora Research Center located in north central New Mexico at an elevation of 2213 m. The frost free season is 100 to 120 days. Mean annual temperature is 6°C and mean annual precipitation is about 51 cm.

The study site is a level valley bottom. Soil is well-drained alluvium with moderate to slow permeability. The upper 50 cm is a dark grayish brown (10YR 4/2) sandy clay loam. According to Cryer (1980) the soil profile classification is Cumulic Haploboroll.

Aspen seed used in this study was collected in early June, 1981, from open-pollinated clones growing from 2500 to 2700 m elevation about 15 km northeast of Santa Fe, New Mexico. At the time catkins were collected, seed release was just beginning on a few branches of sampled trees. Catkins were kept cool (18°C) during and following transfer to a laboratory and "cotton" was released and collected with a vacuum after 20 days. Harder's (1970) extraction procedure was used to remove "cotton" and minute debris. Cottony hairs of the placenta remaining attached to seeds can adversely affect germination (Myers and Fechner 1980). Seed was bulked and stored at -4° C over anhydrous calcium sulfate ("Drierite") in a sealed jar to maintain

seed viability (Benson and Harder 1972). Seed germination was above 90 percent when tested two weeks prior to nursery bed showing.

Installation of experimental nursery beds followed procedures developed by Benson and Einsphar (1962) and modified by Benson and Dubey (1972). Within a 2.44 m x 15.9 m area, five 1.19 m x 2.41 m areas were excavated to a depth of 92 cm for each to accomodate a 1.22 m x 2.44m x 2.44 m wood frame supporting a hinged frame covered with standard window screen. Plywood boards divided each frame into equal quadrants to a depth of 92 cm. Polyethylene plastic lined the main frame soil side walls to the same depth.

The excavated soil was combined with horticulture-grade peat moss to establish four nursery bed growing media: (1) soil; (2) 1/4 peat, 3/4 soil; (3) 1/2 peat, 1/2 soil; and (4) 3/4 peat, 1/4 soil (by volume). In addition, elemental sulfur was added at the rate of 852 kg/ha (750 lb/ac) to each treatment. Physical and chemical properties of media were determined by routine soil test procedures employed by the Soil and Water Testing Laboratory, New Mexico State University.

Each bed frame was covered with plastic to fumigate all experimental plots with methyl bromide. The following day, frame tops were lifted and the beds were aerated for 48 hours.

Aspen seeds were sown at the spacing recommended by IPC (Benson and Dubey 1972) to produce 110-160 seedlings per m^2. Following emergence, excess seedlings were thinned. Beds were irrigated daily by 1.8 cm bi-wall perforated drip tubing. Fertilizer was applied via irrigation water at the rate of 113 kg/ha N, 45 kg/ha P and 79.5 kg/ha K.

Treatments were randomized within frames. Within a 30 cm x 91 cm area centered within each quadrant, 12 seedings were labeled in order to record leaf number and height measurements, repeated at two-week intervals. Seedling density for each of three 30 cm x 30 cm subplots was recorded just prior to harvest.

Seventeen weeks from sowing, seedlings were lifted with a spade and enclosed in plastic bags. Ten trees were harvested from each subplot. Height, caliper, and fresh and oven dry weights were recorded for each seedling. A portable leaf area meter (Li-Cor, Inc.) was used to determine leaf area for 12 of the 30 seedlings harvested from each treatment. Analysis of variance, Duncan's mean separation test, and multiple linear regression were employed in data analyses.

RESULTS

Peat additions progressively improved physical and chemical properties of nursery bed media (Table 1). Most notable are improvements in soil reaction, pore space, hydraulic conductivity, and cation exchange capacity. Organic matter increased considerably but approached the recommended level (3 percent) prior to any addition. In the field, soil peat moss reduced surface crusting and puddling compaction caused by irrigation.

Table 1. Chemical and Physical Properties of Nursery Bed Media

	SOIL	1/4 PEAT (v/v)	1/2 PEAT	3/4 PEAT
Hydraulic Conductivity* (ml/cm^2 - hr)	14.6	30.6	93.3	245.2
Bulk Density (g/cc)	1.23	1.07	0.79	0.44
Pore Space (% By Vol.)	50.8	56.1	68.4	82.4
pH	7.4	6.8	6.0	4.8
% Organic Matter	2.5	4.0	7.9	15.6
C.E.C. (meq/100g)	14.1	15.5	21.0	39.0
Salts (% Sol.)	1.0	1.5	0.9	0.8
N-Total (PPM) (Kjeldahl)	894	1075	1160	2195
NO_3 (PPM)	13.5	22.6	29.9	42.9
P(PPM)	4.4	4.4	5.0	7.6
K(PPM)	11.6	18.5	19.6	29.8

* Before Addition of Sulfur.

Seedlings grown with peat amendments were considerably taller and supported more leaves than those grown in soil alone (figs. 1 and 2). Seedling density averaged 132 per square meter across all treatments and density differences among treatments were not statistically significant at the .05 level. Table 2 compares harvested seedlings across treatments. Most significant is the failure of soil or soil and 1/4 peat to produce a minimum caliper of 0.3 cm (1/8"). Only 3/4 peat produced a 30-cm shoot. Reading across treatments in Table 2, differences for any paired numbers are statistically significant at the .01 level except leaf areas for 1/2 and 3/4 peat.

Multiple regression analysis of the pooled data provided an opportunity for examining growth relations of aspen seedlings. The correlation matrix found in Table 3 shows several parameters

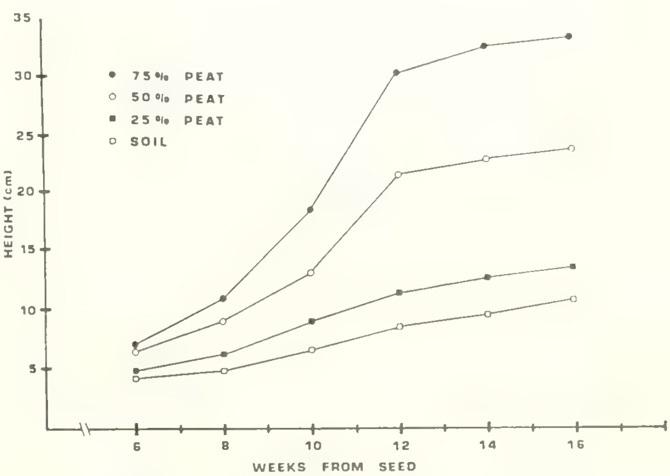

Figure 1. Cumulative Height Growth for Quaking Aspen Seedlings Under Nursery Bed Conditions

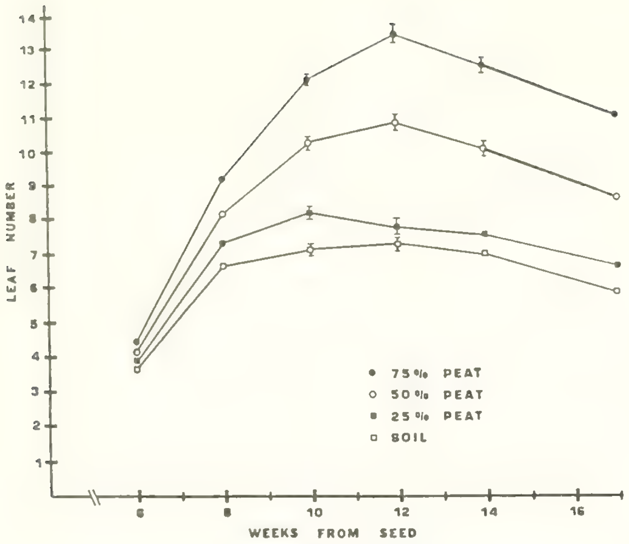

Figure 2. Cumulative Leaf Number for Quaking Aspen Seedlings Under Nursery bed conditions

Table 2. Seedling Growth Responses at 16 Weeks

	SOIL	1/4 PEAT	1/2 PEAT	3/4 PEAT
Height (cm)	10.92	13.60	24.11	33.73
Caliper (mm)	1.94	2.26	3.18	3.95
Leaf Number	5.77	6.73	8.52	11.00
Leaf Area (cm^2)	21.88	30.29	49.32	50.16
Shoot DWT (g)	0.24	0.37	0.98	1.88
Root DWT (g)	0.11	0.22	0.57	0.99

Table 3. Correlation Matrix (R^2)

	Height	Caliper	Leaf No.	Shoot DWT	Root DWT	Leaf Area
Height	--	.86	.74	.81	.67	.22
Caliper		--	.68	.76	.71	.25
Leaf No.			--	.63	.52	.23
Shoot DWT				--	.78	.12
Root DWT					--	.12
Leaf Area						--

to be closely related. Specifically, height is closely related to caliper, leaf number, and shoot weight. All of the values shown are statistically significant (.0001 level).

DISCUSSION AND CONCLUSIONS

The study demonstrated that plantable aspen seedlings can be successfully grown at the Mora Valley nursery site if the soil is amended with peat and sulphur. If the desired caliper is 0.3 to 0.9 cm (1/8" to 3/8"), 1/2 to 3/4 of the nursery medium must be peat if seedlings are grown and harvested in less than 110 days. In the Mora Valley, it would be possible to plant earlier, however, and this would result in larger seedlings. Allowed an additional three weeks, seedlings grown in 1/2 peat may reach desired dimensions.

The relative importance of physical and chemical conditions derived from peat were not determined. However, seedlings grown in peat-amended media were subjected to conditions more favorable than soil for nutrient exchange and uptake, and less favorable for build up of soil pathogens.

Applied over an extensive area, peat amendments would be costly and a local substitute might be sought. In northern New Mexico old composted sawdust can be obtained and may provide a satisfactory substitute (Montano and others 1977). The disadvantages of fresh sawdust and farm yard manure were discussed by Armson and Sadreika (1974), who also recommended peat application rates and procedures.

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GROWTH OF AUSTRIAN PINE AND NORWAY SPRUCE SEEDLINGS IN MINI-CONTAINERS

Houchang Khatamian and Fahed A. Al-Mana

ABSTRACT: Austrian pine (Pinus nigra Arnold) and Norway spruce (Picea abies (L.) Karst.) were seeded in selected mini-containers filled with Jiffy Mix and placed in a greenhouse eighteen weeks from germination. The stem length of both species was greatest in Book Tinus; intermediate in Book Hillson, Square Container and Tar Paper; smallest in Leach Tube, Styroblock 8 and Styroblock 7. The shoot and root dry weight of spruce were greater in smaller containers. Pine seedlings grew equally well in all containers. The ratio of the root dry weight/container volume (mg/cm^3) of both species was higher in the smaller containers.

INTRODUCTION

In recent years, there has been a gradual shift from field-grown, bare-root nursery stock to container production. The increased use of containerized seedlings in nursery and forestry production is due to the advantages of better plant survival and growth, extension of the planting season, and adaptability to mechanical planting. Growth of tree seedlings in mini-containers under controlled-environment conditions has been studied by various workers (Arnott 1974; Barnett 1982; Johnson 1975). Generally, there are three categories of containers used in forestry and ornametal plant production: tube, block, and plug (Barnett 1982). A containerized seedling has a root system which holds the growing medium when removed from the container, and when planted the roots make immediate contact with the soil (Mann 1977). Easy plug extraction depends upon the proper development of the root system, media, moisture content of the plug and the construction of the container walls and ridges (Tinus 1978). Usually, four to five months is needed to produce gro-plug seedlings with root systems suitable for transplanting into larger containers or the field, or for sale (Mann 1977; Thomas 1980).

The design and shape of the nursery containers have been improved recently. Some mini-containers now have vertical ribs or grooves along the container wall with drainage holes at the bottom. The ribs are intended to direct the roots downward and therefore prevent circling of roots (Dickenson and Whitcomb 1978; Tinus and McDonald 1979).

Research has shown that container volume and diameter influence plant growth, and there is a minimum volume below which growth is limited (Wall and Whitcomb 1980). In one study (Venator and Rodriguez 1977), the shoot and root growth of Pinus caribaea var. hondurensis was influenced by the cavity sizes of Styroblock 4 and 8. Similar results were noted for lodgepole pine and white spruce (Carlson and Endean 1976; Endean and Carlson 1975).

Seedlings produced in uniform size mini-containers are adaptable to mechanized planting. The production cost of the containerized seedlings may be higher than field-grown ones, but compensations include faster and superior growth, higher production, longer planting periods and lower labor and land costs. The purpose of this research was to evaluate the effectiveness of selected mini-containers on the rate of seedling growth.

MATERIALS AND METHODS

Austrian pine (Pinus nigra Arnold) and Norway spruce (Picea abies (L.) Karst.) were grown in selected mini-containers to evaluate their effects on seedling growth (table 1). All containers were filled with Jiffy-Mix (commercially available peat-vermiculite 1:1 mix) and placed on wire benches in a glass greenhouse. Four seeds were placed in each cavity. At two weeks after germination seedlings were thinned to one per cavity and at three weeks seedlings were fertilized with liquid 20 N -8.6 P -16.6 K (100 ppm N) once a week and watered every two to three days as needed. The pH of the water was maintained between 5.0-5.5 using phosphoric acid (Tinus and McDonald 1979). The pH and Electrical Conductivity (EC) of the growing medium were monitored before and throughout the trial. Plants were grown for 18 weeks from March to August, 1981, with average day and night temperatures of 30^{o} and $18^{o}C$, respectively.

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Table 1. Container/cavity dimensions

Container Type[1]	Composition	Top Diam. (cm)	Length (cm)	Width (cm)	Depth (cm)	Volume (cm^3)
Styroblock 7[2]	Styrofoam	3.0	--	--	22.5	121.3
Styroblock 8	Styrofoam	3.8	--	--	15.0	131.1
Leach Tube[3]	Polyethylene	3.8	--	--	13.5	131.1
Book Hillson[4]	Polyethylene	--	3.8	3.8	12.5	172.1
Book Tinus	Polyethylene	--	5	3.8	18.1	352.4
Square Bottomless	Unknown plastic	--	4	4	18.9	302.4
Cylinder Tar Paper	Asphalt	6.2	--	--	18.9	570.8

[1]Containers referred to in text as small are, Styroblock 7, Styrobloc, 8, and Leach Tube. Containers referred to in text as large are, Book Hillson, Book Tinus, Square Bottomless and Cylinder Tar Paper.
[2]Styroblock 7 and 8-Silvaseed Company, P. O. Box 118, Roy, Washington 98580.
[3]Leach Tube--Ray Leach Cone-Tainer, 15--N. Maple Street, Canby, Oregon 97013.
[4]Book Hillson adn Book Tinus--Spencer--Lemaire Industries LTD., 11413-120 Street, Edmonton, Alberta, Canada T5G 2Y3.

At the eighteeenth week, the plants were harvested. The development of the root system in each container was visually evaluated. The plant shoots and roots were dried at 65°C for 48 hours for dry weight determination. The experimental design was a split plot in a random block with seven containers and two species replicated four times. The growth rate measurements were determined randomly by selecting six plant samples from each container and species.

RESULTS AND DISCUSSION

Stem Length

Larger containers such as Book Tinus and Tar Paper produced greater stem length for Austrian pine and Norway spruce when compared with the small size cavities of Styroblock 7 (table 2). Possibly the larger diameter of these containers influenced the plant stem length. Similar results were reported for the lodgepole pine and white spruce (Carlson and Endean 1976; Endean and Carlson 1975). Wall and Whitcomb (1980) also reported an increase in seedling height of Lacebark Elm, Atlas Cedar and Japanese Black Pine.

Shoot and Root Dry Weight

With the exception of root dry weight in Tar Paper, the shoot and root dry weights of pine were similar in all containers tested (table 2). Whereas the greatest shoot dry weight of Norway spruce was obtained in the small and tapered containers. According to Endean and Carlson (1975), container configuration (height or diameter) had no effect on shoot dry weight or the shoot length of lodgepole pine seedlings, but it did on white spruce seedling growth. It appears that lodgepole pine and white spruce respond differently to containerized conditions (Carlson and Endean 1976). Spruce is a more shallowly rooted species than pine and therefore had a greater number of roots in the top quarter of the container. In contrast, pine had more roots in the bottom of the container. Austrian pine grew equally well in all containers tested regardless of container configuration and volume. However, Norway spruce seems to grow better in the smaller and tapered containers such as Styroblock 7, Styroblock 8, and Leach Tube, possibly because of its shallow root system.

Shoot/Root Ratio

The shoot/root dry weight ratio of pine seedlings was greatest in Tar Paper which gave the smallest root system (table 2). The Tar Paper was formed as a cylinder which had smooth walls and no ribs. Circulating and spiralling primary lateral roots about the tap root is common in cylindrical containers (Tinus 1978 and Agnew 1981). The main disadvantage observed with the Tar Paper container was the root penetration through the tar paper wall into the adjacent tar paper pots. This makes pot removal difficult, damages the root system and results in loss of roots. This is likely the reason for lower root dry weight of both species grown in Tar Paper containers. Such problems with Tar Paper containers also were noted by Strachan (1974). Norway spruce had a greater shoot/root dry weight ratio in the larger volume containers: Tar Paper, Book Tinus and Book Hillson (table 2).

Root Quality

The extensity,fibrousness, and uniformity of the root system were taken into consideration when visual evaluations on root quality were made. Austrian pine produced a very good root system in all containers tested except for Tar Paper. The root system of spruce was good in Leach Tube, Styroblock 8 and Styroblock 7 (table 2). The plugs of both species indicated a more fibrous and dense root system in Leach Tube and Styroblock containers (fig. 1). The Book planters produced plugs that were quickly and easily extracted (figs. 2 and 3).

Table 2. Effect of various containers on stem length (cm), dry weight (g), root quality and root dry weight/container volume ratio (mg/cm^3) of Austrian pine and Norway spruce seedlings.

Container	Stem Length (cm)	Dry Weight (g)			Root Quality[x]	Root Dry Weight/ Container Volume Ratio (mg/cm)
		Shoot	Root	Ratio		
			Austrian Pine			
Styroblock 7	4.3c[y]	0.92a	0.36ab	2.55c	4.2ab	3.0a
Styroblock 8	4.6bc	1.19a	0.44a	2.70c	4.5a	3.3a
Leach Tube	4.5bc	1.05a	0.39ab	2.69c	4.3a	3.0a
Book Hillson	5.0ab	1.11a	0.34ab	3.26b	4.0ab	2.0b
Book Tinus	5.2a	1.21a	0.41a	2.95bc	3.9ab	1.2c
Square Bottomless	4.7abc	1.24a	0.41a	3.02bc	4.4a	1.4c
Cylinder Tar Paper	4.8ab	1.23a	0.27b	4.55a	3.4b	0.5d
			Norway Spruce			
Styroblock 7	2.8c	0.30ab	0.18ab	1.66bc	3.4ab	1.5a
Styroblock 8	3.0bc	0.32a	0.20a	1.60bc	3.7a	1.5a
Leach Tube	3.0bc	0.27abc	0.19a	1.42c	3.7c	1.5a
Book Hillson	3.1b	0.22cd	0.09c	2.44a	2.1c	0.5b
Book Tinus	3.5a	0.19d	0.09c	2.11ab	2.0c	0.3b
Square Bottomless	3.0bc	0.23bcd	0.14abc	1.64bc	2.8abc	0.5b
Cylinder Tar Paper	3.4a	0.25abcd	0.12bc	2.08ab	2.5bc	0.2b

[z]Means of 24 seedlings from 4 replicates.
[y]Mean separation in columns by Ducan's multiple range test, 5% level.
[x]Visual rating of root system; 1 = poor, 2 = fair, 3 = good, 4 = very good, 5 = excellent.

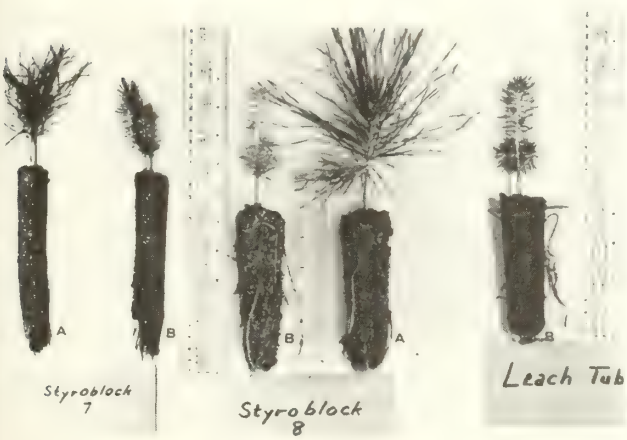

Figure 1. Austrian pine (A) and Norway spruce (B) plugs extracted from Styroblock 7, Styroblock 8, and Leach Tube.

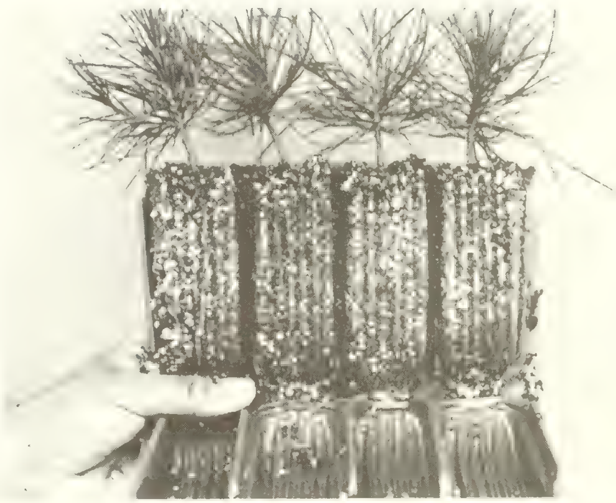

Figure 2. Austrian pine seedlings grown in Book Hillson which can be easily opened to observe the root system.

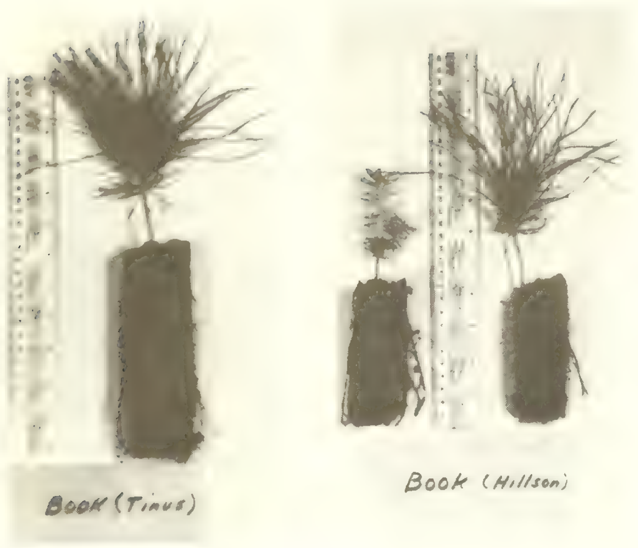

Figure 3. Austrian pine plugs extracted from Book Tinus and Book Hillson. Norway spruce plug of Book Hillson.

The square containers were effective for the production of a good root system in both species (fig. 4).

The smaller and tapered containers produced a more dense root system than the large container by the eighteenth week post-germination. It has been suggested (Allison 1974 and Sjoberg 1974) that the tapered cavity design with rigid and ribbed walls of RL single seedling container (Leach Tube), or the Styroblocks, influences the root growth resulting in fibrous well-developed and balanced root system. Barnett (1982) showed that pine seedlings grown in Styroblocks performed better than those grown in other containers.

CONCLUSION

Selection of containers should be based on the preference of a particular plant species. Smaller and tapered containers such as the Styroblock 7, Styroblock 8 and Leach Tube can be used to grow pine, spruce or similar plant seedlings over shorter periods of up to six months. The larger containers such as the Book and Square may be used successfully over a longer period. Many studies have focused on the effect of container shape and configuration on plant growth, but yet it is not known whether the actual material which containers are made of has any influence on root development and growth. Effects of various types of mini-containers on the seedling performance after transplanting need further research.

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EQUIPMENT FOR REVEGETATING DISTURBED LANDS

Richard G. Hallman

ABSTRACT: Federal land managers find themselves caught between new mining laws that require complete restoration and the difficulty of establishing plant growth in the arid area where mining is occurring. The Bureau of Land Management funded the Forest Service Missoula Equipment Development Center to develop equipment for revegetation. Six equipment systems were developed.

INTRODUCTION

When surface mining for coal in the West began in earnest, about 10 years ago, it became apparent that many techniques developed over the years for improving range habitat were unsuited to revegetate mined land. Surface mining mixes soil profiles, alters surface and ground hydrology, and removes all vegetation. Clearly, new equipment and techniques were needed to restore this land.

The Bureau of Land Management (BLM) of the Department of the Interior (USDI) was the logical Government agency to tackle the problem. About 80 percent of strippable coal in the West is Federally owned, and the BLM manages most of the land where the coal is found. The BLM, along with the Office of Surface Mining, another USDI agency, is responsible for determining the revegetation potential of these lands.

Federal and State mining laws require that restored vegetation equal what existed before mining. Fortunately, coal seams in the West often are thick; seams of 20 feet and more are not unusual. So revenue from mining deposits of that magnitude makes it economically feasible for operators to do the revegetation job that is required.

As part of its effort to develop new revegetation techniques, the BLM turned to the USDA Forest Service Missoula Equipment Development Center (MEDC). MEDC and its sister Center at San Dimas, Calif., were the only equipment development organizations involved in rangeland improvement activities.

In 1975 MEDC personnel began working with the BLM to develop equipment and techniques to revegetate lands under arid and semiarid conditions where establishing vegetation is difficult and expensive. Six pieces of equipment were eventually built to accomplish six specific revegetation tasks. Each piece of equipment is described in the following text. The six equipment systems currently are being evaluated in various locations in the West to perfect the techniques and to establish cost data. For additional information, write USDA Forest Service, Missoula Equipment Development Center, Fort Missoula, Missoula, MT 59801.

DRYLAND PLUG PLANTER

Function

The dryland plug planter (fig. 1) is designed to automatically plant containerized trees and shrub stock on surface-mined reclaimed sites. To insure survival on semiarid sites, the root systems must stay in contact with soil moisture. To help accomplish this, the planter is able to plant containerized stock seedlings that are up to 61 cm long.

Figure 1.--Dryland plug planter plants large container stock; large stock improves survival chances.

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Description

The dryland planter is designed to be mounted on the rear of a tractor. It features hydraulic leveling devices, hydraulic auger with a scarifier, rotating carousel mounted on a movable carriage and two packing spades. The machine plants containerized shrubs or trees quickly and effectively. The leveling devices and high clearance enable operations on rough ground or moderate slopes, while insuring adequate placement. The containerized root system and auger holes allow sufficient moisture uptake and unrestricted root growth for better survival.

The planting is automatic and controlled from the tractor. When the planter is positioned, the platform is leveled with hydraulic cylinders. The auger digs a hole; the scarifier auger then removes any competing vegetation from around the hole. The carousel containing the seedlings rotates and the carriage moves forward on the platform, dropping a seedling into the hole. The packing spades firm the soil around the seedling. Planting rate is estimated at more than one per minute.

Specifications

Carousel capacity: 24 seedlings
Auger diameter: 7.6 to 12.7 cm
46 cm scarifier
Depth: 61 to 76 cm
Power requirements (drawbar): 52 to 75 kW

TREE TRANSPLANTER

Function

The tree transplanter system (fig. 2) was designed to transplant small trees and large shrubs that grow naturally around the mining site to the revegetation area. The trailer is an important part of the system because it greatly reduces overall transplanting costs by reducing the transport time required for each tree. Up to 24 trees per day can be transplanted with the tree transport trailer system. The front-end loader-mounted tree spade is very maneuverable and can negotiate slopes up to 20 percent.

Description

The system consists of a Vermeer Model TS-44A Tree Spade mounted on an Owatonna 880 articulated front-end loader and a specially built trailer consisting of two rows of four cone-shaped pods. The pods are 112 cm in diameter and 108 cm deep.

Eight soil plugs are removed from the transplant site, loaded into the trailer, and transported to the transplant supply area. They are then replaced in the trailer with selected trees and shrubs that are transported back to the transplant site and planted. The front-end loader-mounted tree spade digs the trees or plugs, places them in the trailer pods, and tows the trailer between the transplant site and transplant supply area.

Specifications--Trailer

Overall width: 2.4 m with walkway removed
Height: 2.1 m
Weight: 2,722 kg
Capacity: 8 trees or plugs or 3,922 kg
Cone size: 112 cm diameter, 109 cm deep
Power requirements: 60 kW recommended

Specifications--Tree Transplanter

Ball (cone) depth: 46 to 152 cm
Tree size: to 25 cm diameter (maximum tree size may vary with the type of root structure)
Mounting: tractors, trailers, truck or front-end loaders

Figure 2.--Tree transplanter revegetates reclaimed mine sites with trees and shrubs.

DRYLAND SODDER

Function

The dryland sodder (fig. 3) transfers native topsoil from the mine area to the reclamation area with its structure, profile, and vegetation intact. Reclamation is greatly enhanced because the soil horizons are not mixed, so soil development does not have to be repeated.

The dryland sodder strips the top layer of soil and vegetation (sod, forbs, shrubs, and small trees) from areas to be surface mined and places it intact over reshaped areas. The soil layer is scooped into the sodder and transported to the reclamation area. It is removed by tilting and shaking the bucket while slowly moving the loader backward. The conveyer system will feature hydraulic control of the conveyor rollers, allowing the sod to be removed without tilting the bucket.

Description

The dryland sodder is a modified front-end loader bucket. The side walls and back wall are vertical to minimize damage to shrubs and tree seedlings that are stripped along with the soil and sod. The wide, flat bottom of this bucket is sprayed with plastic to reduce friction. A conveyor system is being developed for the bottom of the dryland sodder to aid loading and unloading of the sod strips and to prevent excess soil separation during the transfer.

Specifications

Width: 4.3 m
Length: 2.4 m
Depth: to 30 cm
Power requirements (flywheel) 80 to 391 kW

Figure 3.--Dryland sodder preserves topsoil and its vegetation for later replacement on reshaped spoil materials.

SPRIGGER

Function

The sprigger (fig. 4) undercuts and gathers sprigs, or portions of rhizomatous stems, that can produce roots and shoots. The harvested sprigs are then spread out on the area to be revegetated and covered with soil.

Description

The sprigger is a modified potato harvester. It consists of an undercutting blade and a pair of wide, inclined conveyors. The conveyors are long rods attached between two chains and spaced 3.8 cm apart. A third conveyor across the top of the machine moves the harvested material to the side where it is dumped into a truck or piled in windrows. The sprigger is towed and powered by a tractor.

After the shrubs are mowed, the sprigger is pulled through the stand, cutting the roots well below the ground surface. The cutting action lifts the soil and shrubs onto the conveyors. The soil is shaken loose and falls through the spaces in the conveyors to the ground. The bareroot rhizomatous shrubs, or sprigs, are gathered and carefully planted on the reclamation area.

Specifications

Width: 1.5 m
Depth: 30 cm
Power requirements (drawbar): 60 to 75 kW

Figure 4.--Sprigger digs up rhizomatous material for planting on reclaimed areas.

BASIN BLADE

Function

The basin blade (fig. 5) scoops out large basins or depressions along slopes. Moisture accumulates in these basins to provide a favorable microsite for plant growth. The large basins reduce wind erosion. They also provide the advantages of terracing with fewer hazards and less expense. They collect runoff and trap snow and blowing topsoil. The furrows formed by the scarifying teeth help retain broadcast seed and fertilizer and promote increased infiltration.

Description

The basin blade is a large, crescent-shaped, heavy steel blade mounted on the rear of a crawler tractor. The blade is mounted on a parallelogram multiple-ripper shank. It is raised, lowered, and tilted hydraulically. Several replaceable scarifying teeth are located along the bottom edge of the blade.

The tractor is driven along the contour of a slope and the blade is periodically raised and lowered to form large depressions. Seed is then broadcast along the slope.

Specifications

Width: 3 m
Depth: to 91 cm
Power requirements (flywheel) 216 to 276 kW

Figure 5.--Basin blade makes depressions in soil that trap moisture, creating favorable conditions for plant growth.

HODDER GOUGER

Function

The gouger (fig. 6) creates numerous depressions in the soil surface. These depressions provide a suitable microclimate for plant establishment by increasing moisture availability, reducing wind and water erosion, and providing shade.

Description

The gouger consists of three to five semicircular heavy steel blades attached to solid arms. Each blade has three scarifying teeth along the bottom edge. The arms are attached to a heavy-duty frame with spring-loading mechanisms. They may be mounted in either one- or two-row configurations. The frame is supported with side wheels that are periodically raised and lowered to allow the blades to scoop out depressions. The unit is operated hydraulically and features positive depth control and automatic up and down cycling. A seedbox spreader is mounted on the rear of the machine to broadcast seed into the depressions.

The gouger is towed behind a tractor. The hydraulically powered automatic cycling system moves the frame up and down in relation to the wheels to create depressions. The depth of the depressions, cycle rate, and blade configuration can be varied to suit the site conditions. Average production rates have varied from 1 to 1.1 ha per hour.

The gouger creates more and larger depressions than similar equipment. The automatic cycling and hydraulic depth control make it easier to operate and the adjustable cycle rate and variable blade configurations contribute to its versatility. The spring-loaded blade arms enable it to operate in fairly rocky ground.

Specifications

Implement width: 3.4 m
Depression width: 38 to 56 cm
Depression length: 0.9 to 1.2 m
Depth: 15 to 25 cm recommended
Power requirements (drawbar): 37 kW minimum

Figure 6.--Hodder gouger makes depressions in soil and simultaneously seeds area to establish plant cover.

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PRELIMINARY TRIALS ON UPGRADING *PLATANUS OCCIDENTALIS*

WITH THE HELMUTH ELECTROSTATIC SEED SEPARATOR[1]

Robert P. Karrfalt and Richard E. Helmuth

ABSTRACT: The electrostatic seed separator is a recently invented seed conditioning machine which uses the force of an electrostatic field to separate particles of different area and weight. It has been successfully used to size, clean, and improve germination of *Platanus occidentalis* seed. The seed separator also should be useful on other tree seed.

INTRODUCTION

Upgrading refers to steps that exceed basic cleaning which improve the quality of seed. Therefore, upgrading includes removing empty seed, fungus or insect damaged seed, and stones or pitch. Sizing seed can also be considered upgrading because speed of germination can vary for different seed sizes. Several authors have stressed the importance of upgrading and how to accomplish it (Belcher 1978; Bonner 1978).

Sycamore (*Platanus occidentalis* L.) seed is generally low in viability and difficult to upgrade because of its small size. The electrostatic seed separator was tested on sycamore to determine how it might resolve this problem.

Principles of Electrostatic Separator

An elementary demonstration of the electrostatic movement of particles includes lifting particles of paper with a piece of plastic that has been charged by rubbing it with a dry cloth. The paper is drawn to the plastic by an electrostatic field. Heavier seed can be separated from lighter seed by the same principle if the strength and design of the electrostatic field is carefully controlled.

The Helmuth electrostatic seed separator consists of a hanging electrode and adjustable ground plates (fig. 1) Voltage applied to the stationary electrode creates an electrostatic field between the electrode and the ground. As seed is poured between the ground and the electrode by the vibratory feeder, the static field carries the lighter seed and impurities towards the ground. The stronger the static field, the farther the particles will be pulled. The strength of the field is controlled by adjusting the voltage applied to the electrode. For each seed lot, there is a voltage that produces a maximum distance between the lightest and heaviest seeds being separated. This voltage must be determined by trial during processing just like adjusting other seed conditioning equipment. Using a voltage higher than the one producing the maximum speed will only move all the seeds closer to the movable ground and not give any better separation. The purpose of the ground's mobility is to adjust the distance so the seed can separate. When the seeds have reached the bottom of the static field, they are collected in a tray. Adjustable vanes in the collection tray keep the fractions separated.

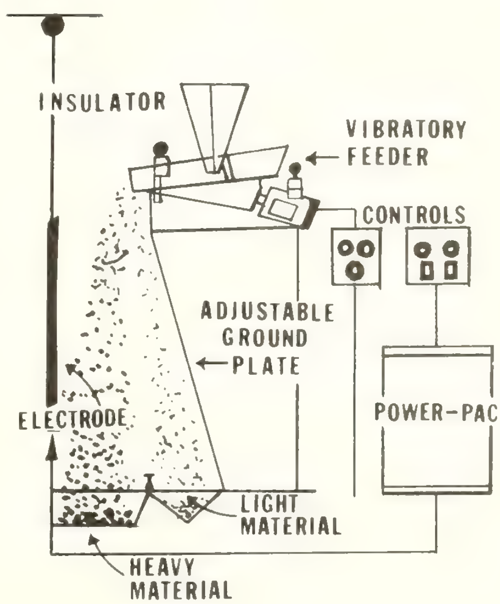

Figure 1.--Diagram of the electrostatic seed separator.

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Richard E. Helmuth is inventor of the electrostatic seed separator and President of the Helmuth Corporation, Carmel, Ind.

[1]Mention of trade names is only to identify equipment used and does not imply endorsement by the U.S. Department of Agriculture. U.S. patents have been granted on this equipment.

MATERIALS AND METHODS

[illegible] slotted screen on top and a number 7 round hole screen on the bottom. This removed the bulk of the fluff which prevented the seed from flowing freely. A portion of seed was taken from the tester and designated as the original sample. This original lot was upgraded on the Helmuth electrostatic separator. The electrode is 80 cm x 130 cm. Voltage can vary from 0 to [illegible],000 volts to accomodate many particle sizes. The voltage setting and feed rate established by preliminary trials and x-ray analysis will determine full seed percentages. Although voltages are high, no danger can occur to the operator if the machine is used properly.

After the preliminary trials, six fractions were obtained from the original lot. Each fraction was evaluated for germination, Czabator's germination value (Czabator 1962), purity, full seed percentage, and seed per pound. Tests were conducted according to the Association of Official Seed Analysts' rules. Stratification was for 60 days at 3°C on the germination media. Germination was on crepe cellulose paper with a temperature of 20°C at night and 30°C during the 8 hour day. Germination counts were made daily; the final count was made on day 12. There was no statistical analysis. Table 1 presents the [illegible].

RESULTS AND DISCUSSION

Notable accomplishment was made with all seed quality measurements. The results are summarized in table 1. Purity was improved from 88 to 99 percent or better, and full seed percentage from 34 to a maximum of 52. The larger seed are almost twice as big as the smaller seed. The best germination was 18 percent better than the original lot. The largest three sizes of seed were also the most vigorous as shown by their sizeable germination values.

The improvement in viability and vigor is best understood by examining the data on a full seed basis (table 2). The pattern in germination is substantially modified. Instead of the best lot germinating 25 percent higher than the poorest lot, it is only 7 percent better on a full seed basis. The computed germination value, using full seed data, is actually higher for the smaller seed. This is because the smaller seed reached 90 percent of their total germination sooner than the larger seed. Therefore, the higher full seed percentage of the best lots is largely responsible for the better germination and germination values.

Removal of empty seed was not, however, the only effect of the seed separator. The fact that the smaller seed germinated the fastest, shows there were also physiological differences among the seed sizes.

Table 1.--Seed test results of the original seed lot and the six samples obtained by electrostatic seed separation. Values are based on actual germination data.

FRACTION #	ORIGINAL	1	2	3	4	5	6
ACTUAL GERMINATION	[illegible]	48	40	43	37	33	23
GERMINATION VALUE	8.23	22.28	16.65	18.94	15.92	13.28	7.05
PERCENT FULL SEED	34	52	46	46	40	37	26
[illegible] POUND (M)	147.0	94.9	99.0	101.7	118.7	152.2	168.0
[illegible]	88	99	99	100	100	100	100
DAYS TO REACH [illegible] OF TOTAL [illegible]	[illegible]	[illegible]	8	8	7	7	6

Table 2.--Germination and germination value computed on full seed basis.

FRACTION #	ORIGINAL	1	2	3	[illegible]	[illegible]	[illegible]
GERMINATION	88	92	87	[illegible]	[illegible]	[illegible]	[illegible]
GERMINATION VALUE	71.7	82.15	78.66	88.53	100.75	[illegible]	[illegible]

According to the data obtained, the electrostatic separator appears to have definite potential to effectively upgrade small tree seed. Other species that might be effectively upgraded would include birch, sweetgum and conifers such as white spruce. In a preliminary trial, redwood purity was visually much improved with the Helmuth separator. There were no laboratory test data. In the nursery, the upgraded seed will give more uniform germination and provide more uniform seedling densities, greater numbers of plantable seedlings per pound of seed, and more efficient use of nursery space.

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SURVIVAL, GROWTH, AND ROOT FORM OF CONTAINERIZED JEFFREY PINES

TEN YEARS AFTER OUTPLANTING

J. D. Budy and E. L. Miller

ABSTRACT: To evaluate the effect of various containers on survival and growth, trials established in 1973 were remeasured in 1983. In addition, 20 seedlings were excavated in order to determine the effect of container type on root development. After 10 years, the container type had a significant effect on survival and height growth. Root form and the number of lateral roots were also influenced by container type.

INTRODUCTION

Since the early 1970's, containerized seedling systems have been developed and tested throughout the United States. The early work was concerned largely with the development of an acceptable and suitable container. Early experimental container types were available in various sizes, shapes and materials. These containers were either planted with the seedling or removed just prior to planting. Over the past decade, evaluation of the various containers has been based on early field performance, production costs, and technical problems.

The rapid evolution of container planting systems both in Canada and the U.S. resulted in a tremendous need to transmit research findings. Fortunately, much of the information has been made available through conference proceedings. In 1971, the Canadian Forestry Service sponsored a workshop on container planting (Waldron 1972). The first international conference held in Denver brought together much of the knowledge and expertise available on containerized seedlings (Tinus and others 1974). Two symposia held in 1981, the Southern Containerized Forest Tree Seedling Conference (Guldin and Barnett 1982) and the Canadian Containerized Tree Seedling Symposium (Scarratt and others 1982), updated much of the available information on containerized seedling systems.

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Although information has rapidly accumulated since the early 1970's, long term studies on growth and development are lacking. The development and evolution of containerized systems will be influenced by biological performance under field conditions. Considerable discussion has dealt with the potential problem of root deformation resulting from container designs. Although a symposium was devoted to the root form of bareroot and containerized seedlings (Van Eerden and Kinghorn 1978), the overall effect of root configuration on field performance is still not well documented. The primary objective of this paper is to report on ten year survival, growth, and root form of containerized seedlings outplanted on adverse sites.

METHODOLOGY

The materials and methods used in establishing the original trial in 1973 are discussed in the North American Containerized Forest Tree Seedling Symposium (Miller and Budy 1974). Survival, height, and root collar diameter were measured in June 1983. Five seedlings of each container type were excavated by hand in order to recover the root system extending 30cm from the container. No attempt was made to recover the entire root system. After excavation, the number of lateral roots extending from the container sidewalls was recorded and the diameter of the tap root at the bottom of the container was measured. The seedling was severed at the root collar, and shoot and root green weights were determined.

Containers

The container types included in the 1973 trial and reevaluated in 1983 are described in Table 1. The Japanese paperpot is designated FH520. The Conwed is an open-mesh, nonbiodegradable polypropylene plastic material. The Conwed designated as 9+3 in this paper contained 9-inches of potting mix with 3-inches of the plastic mesh left exposed above the soil surface when planted. The Zeiset containers are made of a polyethelene coated board stock paper, similar to that used in milk cartons. The polyetheylene coating (.0005 inch) is intended to keep plants divided while in the greenhouse, but not thick enough to girdle plants when outplanted in the field.

Table 1.--Description of containers evaluated.

Container Type	Dimensions Dia. (in)	Depth (in)	Dia. (cm)	Depth (cm)	Material	Rooting Volume (in³)	(cm³)
8-Paperpot	2.0	7.9	5.0	20.0	Treated paper	25.1	392.7
9+3-Conwed	2.0	9.0	5.0	22.9	Plastic mesh	28.3	463.3
12-Conwed	2.0	12.0	5.0	30.5	Plastic mesh	37.7	617.8
12-Zeiset	2.5[1]	12.0	6.4[1]	30.5	Polyethylene cover - ed cardboard	75.0	1229.0

[1]Side of square.

RESULTS

Survival and Growth

After 10 years, the survival was very similar to the first year survival (Table 2). Compared to the losses encountered during the first year, subsequent mortality was relatively low. The highest survival and best growth after 10 years were evident with the Conwed containers. The results indicated a highly significant difference ($P < .01$) in survival between the Conwed containers and the paper and cardboard containers. After nine years the difference in heights was apparent, but not significant. The significant difference ($P < .05$) in height growth was not revealed until after ten years. The seedlings in Zeiset containers showed the lowest height and diameter growth. The poor field performance of the Zeiset seedlings appears to be related to the root form and is discussed in the following section.

Root Form

Excavation of the containerized seedlings revealed that field performance may be largely affected by the design and shape of the container. Representative root systems after excavation are shown for the 12-Conwed (Fig. 1), 9+3-Conwed (Fig. 2), 12-Zeiset (Fig. 3), and 8-Paperpot (Fig. 4). The most obvious difference between the four container types is the lack of lateral roots penetrating from the Zeiset container.

The only container type which showed any signs of breaking down was the Paperpot. The Zeiset containers were still very much intact and it appeared that the plastic coating was very effective in preventing lateral root development. The Conwed containers were not expected to break down; however, as the lateral roots developed they were able to break apart the plastic mesh (Fig. 5). Although the roots showed signs of constriction (Fig. 6), the developing lateral roots can apparently overcome the obstruction.

Table 2.--Mean survival, diameter and height of Jeffrey pine seedlings outplanted in 1973.

Container Type	Survival[1] 1974	Survival[1] 1983	Diameter[2] 1983	Height[1] 1983
	(%)	(%)	(cm)	(cm)
9+3-Conwed	80[a]	63[a]	3.3	77[a]
12-Conwed	76[a]	61[a]	3.1	70[ab]
12-Zeiset	59[b]	39[b]	2.3	51[b]
8-Paperpot	50[b]	34[b]	2.5	57[ab]

[1]Means with the same superscript are not significantly different.
[2]Diameter at root collar.

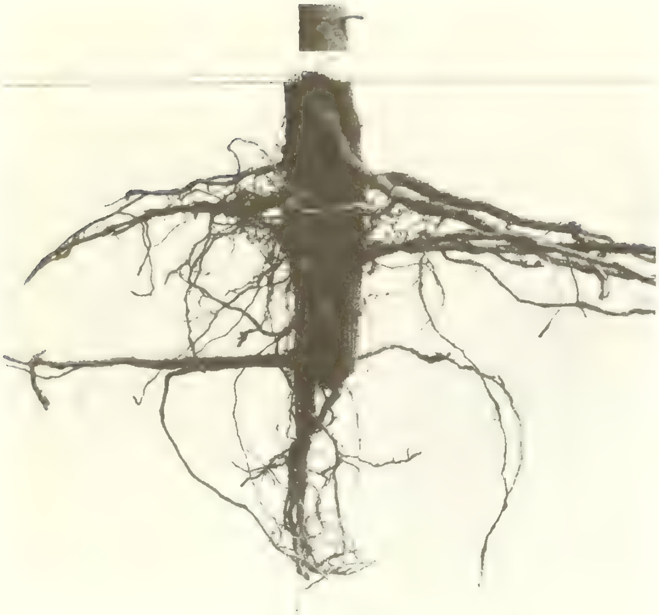

Figure 1.--Root penetration of a Jeffrey pine through a 12-Conwed ten years after outplanting.

Figure 2.--Root Penetration of a Jeffrey pine through a 9+3-Conwed ten years after outplanting.

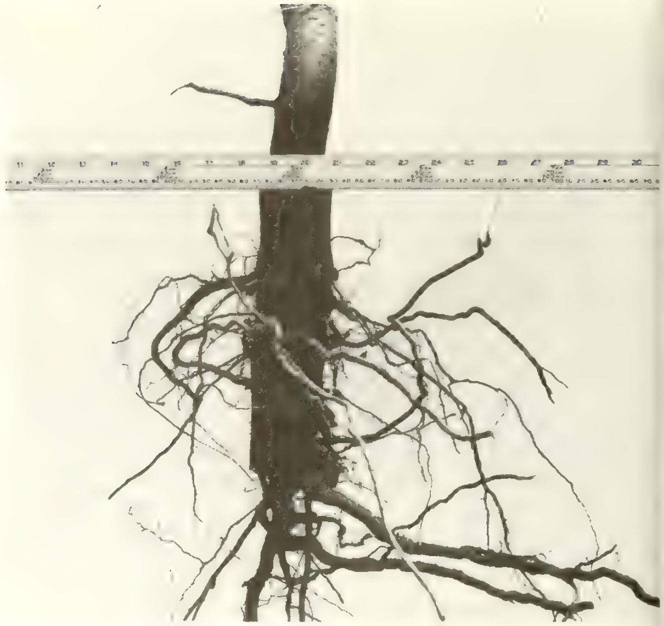

Figure 3.--Root penetration of a Jeffrey pine through a 12-Zeiset ten years after outplanting.

Figure 4.--Root penetration of a Jeffrey pine through a 8-Paperpot ten years after outplanting.

Characteristics of the excavated seedlings are shown in Table 3. The Conwed seedlings had a greater number of lateral roots penetrating through the container sidewalls, a larger tap root emerging from the bottom of the container, and a greater biomass than the Zeiset and Paperpot seedlings. There was a highly significant difference ($P < .01$) in the mean number of lateral roots between the Conwed and both the Zeiset and Paperpot seedlings (Table 3). Also, the Paperpot seedlings had significantly ($P < .01$) greater root penetration through the sidewalls than the Zeiset seedlings. The lack of lateral root penetration for the Zeiset seedlings may account for the poor field performance. In addition, after the containers were removed from the excavated seedlings (Fig. 7-10), root problems were most evident on the Zeiset seedlings. Although the Zeiset seedlings developed lateral roots (Fig. 11), the laterals were confined within the container and became quite deformed after ten years of restricted growth (Figure 12).

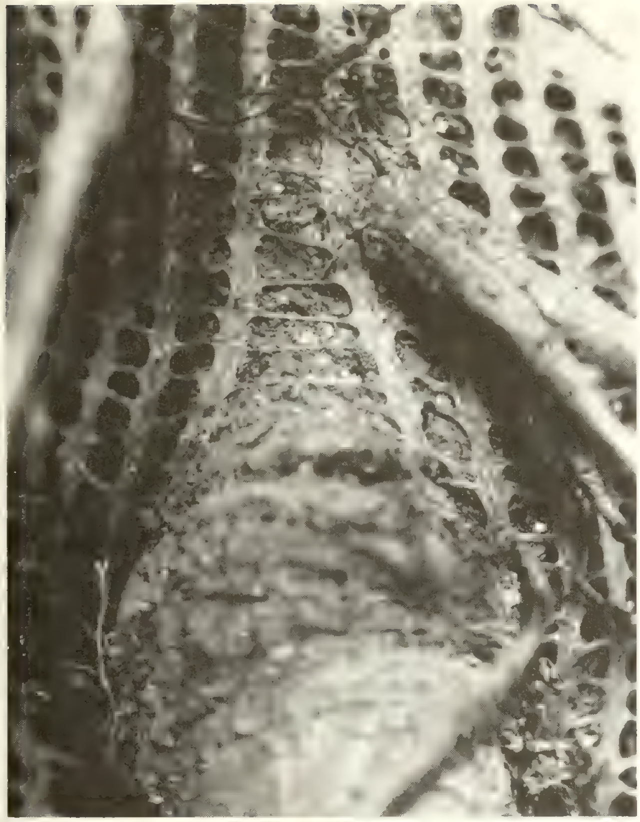

Figure 5.--Close-up view of a lateral root breaking apart the plastic mesh of a Conwed Container.

Figure 6.--Lateral Root of a Jeffrey pine showing constriction resulting from the plastic mesh of a Conwed container ten years after outplanting.

Table 3.--Mean root and shoot characteristics of excavated Jeffrey pines ten years after outplanting in four container types (5 samples per container type).

Container Type	Lateral Roots[1]	Tap Root Diameter	Green Weight Root	Green Weight Shoot
	(no.)	(cm)	(kg)	(kg)
9+3-Conwed	19.6[a]	2.12	.381	1.39
12-Conwed	19.6[a]	2.24	.406	1.60
12-Zeiset	.6[b]	.99	.227	.73
8-Paperpot	11.0[c]	1.26	.112	.42

[1]Means with the same superscript are not significantly different.

DISCUSSION

The results of this study indicate some interesting, as well as significant, findings regarding the relationship between container type and field performance. The highest survival and best growth occurred on those seedlings outplanted in Conwed containers while the poorest survival and growth occurred on the Zeiset and Paperpot containers. The most significant finding was the lack of lateral root penetration through the Zeiset containers. Although the manufacturer's intention with the plastic coating is to keep the plant roots divided during the rearing stages in the greenhouse, the thin coating apparently prevents lateral roots from penetrating through the sidewalls, even ten years after outplanting. The manufacturer does recommend punched holes for quicker lateral root extension on containers longer than four inches. The results of this study support the recommendation.

More importantly, and perhaps of significance in the development and evolution of an acceptable container, was the relationship between growth and lateral root development. In this study, the best growth was obtained on seedlings outplanted in containers where lateral root development was unrestricted. The poorest growth resulted where lateral root development was restricted. Owston and Stein (1978) reported the poorest growth after seven years on Douglas-fir and noble-fir outplanted in one-quart milk cartons. Although their studies were conducted on favorable sites, the milk cartons remained intact and the main laterals were almost entirely contained within the carton. They also reported greater height growth on seedlings outplanted in Conweds than in either milk cartons or cardboard tubes. Tinus (1978) has suggested that holes or slits be incorporated into the upper sides of solid wall containers to increase surface laterals for wind firmness; however, the results of this study indicated that better growth and development resulted where lateral root development was unrestricted.

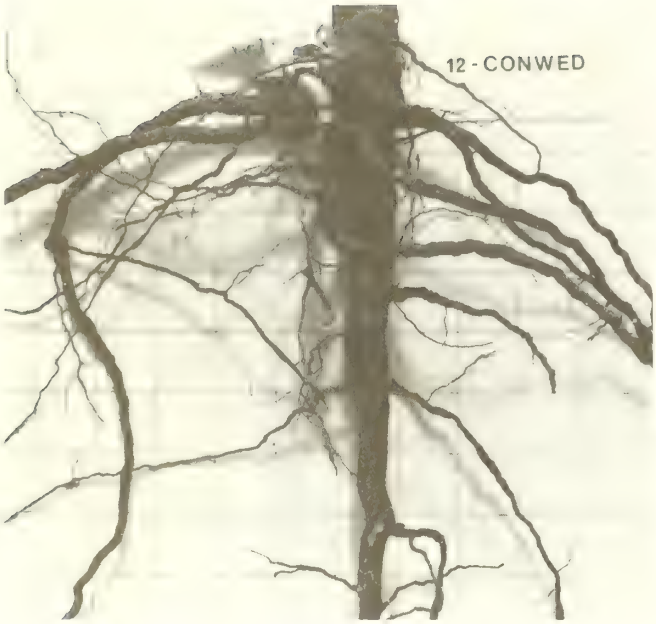

Figure 7.--Root system of a Jeffrey pine with the 12-Conwed container removed ten years after outplanting (grid = 4x4cm).

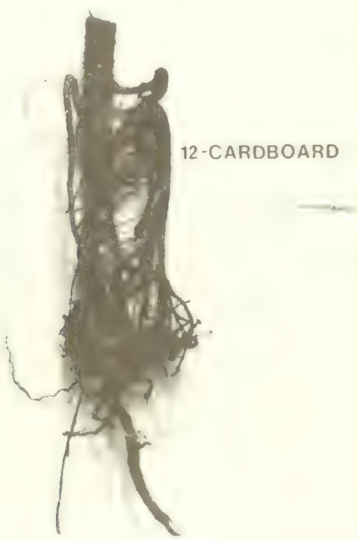

Figure 8.--Root system of a Jeffrey pine with the 9+3-Conwed container removed ten yers after outplating (grid = 4x4cm).

The growth and development of seedlings outplanted in Conwed containers also dispel some of the early fears of root constriction problems associated with the plastic mesh type of container. Although Barnett (1982) reported that loblolly pine roots can become severly constricted by the plastic mesh three years after outplanting, the results

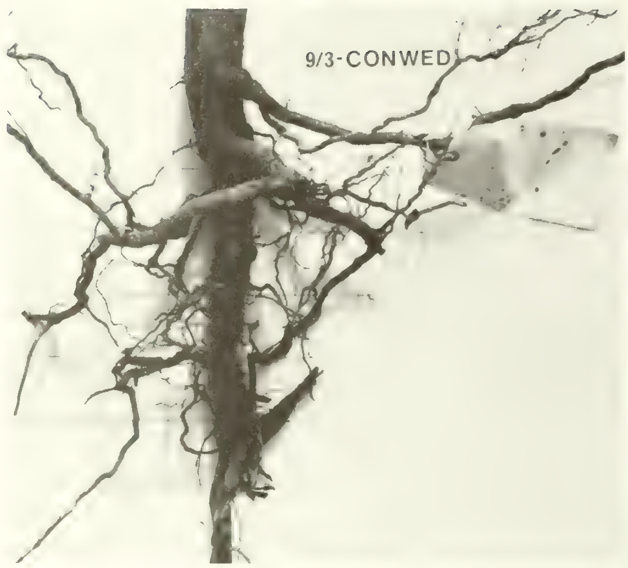

Figure 9.--Root system of a Jeffrey pine with the 12-Zeiset container removed ten years after outplanting (grid = 4x4cm).

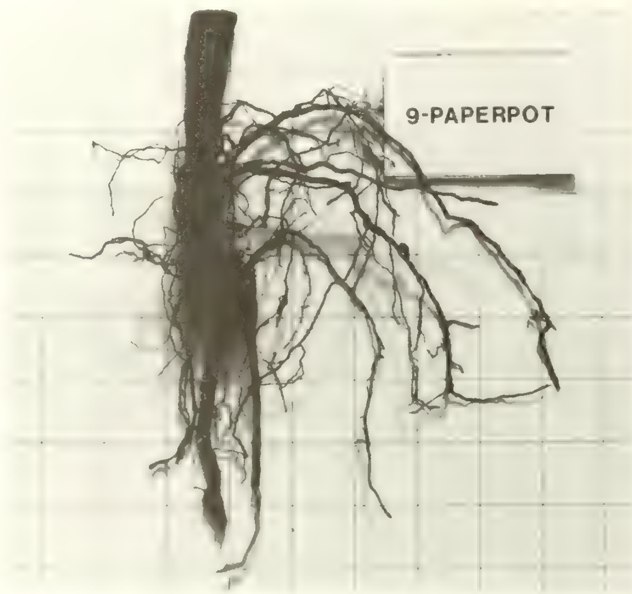

Figure 10.--Root system of a Jeffrey pine with the 8-Paperpot container removed ten years after outplanting (grid = 4x4cm).

of this study indicated that the lateral roots can break apart the plastic mesh. The Conwed material has been manufactured in various degrees of flexibility, and the material used in Barnett's study was less flexible than the material used in this study. Owston and Stein (1978) tested the same Conwed material as used in this study

Figure 11.--Jeffrey pine root system showing the restriction of lateral root development after ten years in a 12-Zeiset container (grid = 4x4cm).

Figure 12.--Close-up view of a Jeffrey pine root system showing deformation after ten years in a 12-Zeiset container (grid = 4x4cm).

and reported girdling on the lateral roots. They found that the lateral roots penetrating the plastic mesh were smaller in diameter than those penetrating peat-fiber pots. The root constriction problem associated with plastic mesh containers may reduce growth somewhat; however the problem appears to be relatively minor and apparently short-lived compared to the root restriction problem associated with solid wall containers.

CONCLUSIONS

The acceptance of a container type for any system will depend on a number of variables. The field performance of outplanted seedlings will help evaluate the containers presently available and will aid the development of future containers. The higher survival and better overall growth obtained with the plastic mesh containers suggest the importance of unrestricted lateral root development. The root constrictions which did appear on the laterals due to the plastic mesh did not appear to adversely affect the seedling growth and development compared to the effect of restricted lateral root development found on the cardboard containers. Although a biodegradable plastic mesh container would appear promising, the relatively high cost of biodegradable plastic has discouraged further development (Barnett 1982; Barnett and McGilvroy 1981).

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GROWING CONTAINERIZED TREE SEEDLINGS IN A SHADEHOUSE

Thomas M. Smith

ABSTRACT: Initial data indicate containerized ponderosa pine (Pinus ponderosa, Rocky Mountain form) tree seedlings germinated in a greenhouse in early May can be moved to a shadehouse in early June and successfully grown in Albuquerque, N.M. Data also indicate that ponderosa pine seedlings sown in early February can be removed from the greenhouse in early May rather than early June and may survive a July outplanting at the same location.

INTRODUCTION

On May 2, 1983, three baskets of seed, each containing 13 Spencer-LeMaire, Tinus (21.5 cubic inches) bookplanters, were sown at the Bureau of Indian Affairs (BIA) greenhouse in Albuquerque, N.M. A Zuni, N.M., seed source was used. Two seeds per cavity were sown. There was a crop of ponderosa pine (Pinus ponderosa, Rocky Mountain form) containerized tree seedlings present in the greenhouse that had been sown in early February 1983, therefore, germination conditions were not optimum. The production greenhouse currently maintains a triple crop schedule producing approximately 79,000 containerized tree seedlings per crop. The purpose of this study was to determine the potential for four crops annually. On May 3, 1983, two baskets each containing 52 containerized tree seedlings were removed from the greenhouse and placed in the shadehouse. These baskets were part of the crop that was sown in early February 1983, and were from a Zuni, N.M. seed source. It was felt that the weather was too cold to move the seedlings into the shadehouse earlier.

DISCUSSION AND RESULTS

The BIA facility in Albuquerque, N.M., is a 30' x 100' double poly nexus style greenhouse with a shadehouse approximately 100' x 100'. The fertilizer used is Peters 20-20-20 for the greenhouse, Peters 9-45-15 for after-stress and in the shadehouse, and Peters STEM for trace element addition in both the greenhouse and shadehouse.

In an attempt to determine if crop production could be increased, two baskets of seed, each containing 13 Spencer-Lemaire Tinus (21.5 cubic inches) bookplanters, were sown on May 2, 1983. These baskets of seeds were then placed with a crop of ponderosa pine containerized tree seedlings that were sown in early February 1983. All seedlings were from a Zuni, N.M., source.

The germinants were watered twice daily with the boom during scheduled waterings and supplemented with hand waterings for two weeks. No watering was done on the weekends.

Table 1 lists the daily temperature extremes in the greenhouse from May 2 to June 7, 1983.

Table 1.-- Greenhouse maximum, minimum, and current temperatures from 5/2/83 to 6/7/83

Date	Time	Max.	Min.	Current
5/2	0733	84	76	78
5/3	0720	80	68	71
5/4	0739	82	69	72
5/5	0727	80	70	72
5/6	0740	83	70	72
5/7	1159	78	69	76
5/8	1200	78	70	78
5/9	0729	84	70	72
5/10	0739	80	70	73
5/11	0735	82	70	73
5/12	0738	81	70	76
5/13	0740	80	70	71
5/14	0800	78	70	78
5/15	0800	79	71	78
5/16	0740	81	70	74
5/17	0735	79	70	72
5/18	0735	78	71	73
5/19	0730	78	71	74
5/20[1]	0740	80	71	72
5/23[2]	0722	78	62	66
5/24	0735	82	63	66
5/25	0740	87	62	65
5/26	0725	84	65	66
5/27	0730	88	63	64
5/28	0800	80	63	68
5/29	0800	85	64	67
5/30	0814	80	64	68
5/31	0745	77	62	64
6/1	0735	78	60	62
6/2	0740	79	60	62
6/3	0734	80	58	60
6/4	0800	77	57	65
6/5	0800	81	58	64
6/6	0730	82	63	64
6/7	0715	78	62	63

[1] Hygrothermograph clock stopped during evening of 5/20/83 and no recordings available until 5/23/83.

[2] May 23, 1983, the greenhouse crop was flushed then stressed; germinants were neither flushed nor stressed.

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The temperatures that were maintained in the greenhouse were within the optimum range for seedlings in the "exponential" stage, but they were not optimum for "germination."

During stressing the germinants were watered Monday, Wednesday, and Friday morning, and were fertilized within one tablespoon/gallon 20-20-20.

The greenhouse crop and germinants were moved to the shadehouse on June 7, 1983.

In the shadehouse the germinants received the following:

A. June 8 - water and fertilize with shadehouse 2 lb. 9-45-15+STEM/6 qt. water.
B. June 10- water from greenhouse lines.
C. June 13 - water and fertilize with shadehouse 2 lb. 9-45-15+STEM/6 qt. water.
D. June 15 - water from greenhouse lines.
E. June 16 - water and fertilize with shadehouse 2 lb. 9-45-15-STEM/6 qt. water.
F. June 17 - water from greenhouse lines, fertilize 1 tablespoon/gal. 20-20-20.
G. June 20 - water and fertilize with shadehouse 2 lb. 9-45-15+STEM/6 qt. water.
H. June 22 - water from greenhouse lines, fertilize 1 tablespoon/gal. 20-20-20.
I. June 27 - water and fertilize from greenhouse lines, 1/2 lb. 20-20-20+STEM/4 qt. water.
J. June 29 - water and fertilize from greenhouse lines, 1/2 lb. 20-20-20+STEM/4 qt. water.
K. July 1 - water from greenhouse lines.
L. July 4 - water and fertilize from greenhouse lines, 1 lb. 20-20-20+STEM/4 qt. water.
M. July 6 - water and fertilize from greenhouse lines 1 lb. 20-20-20+STEM/4 qt. water.
N. July 7 - water and fertilize from shadehouse lines,2 lb.9-45-15+STEM/6 qt. water.
O. July 11 - water from greenhouse lines, fertilize 3 tsps./gal. 20-20-20.
P. July 13 - water and fertilize from greenhouse lines, 1/2 lb. 20-20-20+STEM 4 qt/ water.
Q. July 15 - water from greenhouse lines.
R. July 18 - begin water and fertilize from greenhouse lines, 2 lb. 20-20-20+STEM.
S. Continue watering schedule of 7/18 on Mondays and Wednesdays, and water only from greenhouse lines on Fridays

Table 2 records the measurements of the germinants as of August 1, 1983.

Table 2.--Measurements of germinants, August 1983

Basket No.	Caliper (Inches) Max.	Min.	Mean	Mode	Median
1	3/32	1/16	0.067	1/16	1/16
2	3/32	1/32	0.067	1/16	1/16
3	3/32	1/16	0.066	1/16	1/16

Basket No.	Height (Inches) Max.	Min.	Mean	Mode	Median
1	4 7/8	1 1/2	3.983	4	4
2	4 7/8	1 3/4	3.635	3 1/2	3 5/8
3	5 3/8	2 1/2	3.756	3 1/4	3 1/2

Basket number 1 contained 52 seedlings, basket number 2, 51, and basket number 3 contained 50. The maximum possible number of seedlings was 52 per basket.

Containerized tree seedlings are grown for spring and summer outplanting. Seedlings sown in the summer are scheduled for outplanting the following spring. The goal of the summer sowing is to produce a seedling that would successfully overwinter in the shadehouse. Currently the seedlings are actively growing and have good secondary needle development. Chronologically, these seedlings are one month older than those in the greenhouse. They are further developed in all phases of growth than those that have been in a fully controlled greenhouse for two months.

On May 3, 1983, two baskets, each containing 52 ponderosa pine containerized tree seedlings were moved to the shadehouse. These seedlings were sown in early February 1983 from a Zuni, N.M., seed source. The seedlings were not moved to the shadehouse until low temperatures could be assured to be above 32°F.

Table 3 details daily Fahrenheit temperature ranges in the shadehouse.

Table 3.--Daily maximum, minimum, and current shadehouse temperatures from 4/29 to 6/7/83

Date	Time	Max.	Min.	Current
4/29	1553	85	39	85
5/2	1615	87	35	66
5/3	1630	88	33	74
5/4	1558	92	33	87
5/5	1615	90	36	88
5/6	1556	87	40	80
5/9	1617	88	40	80
5/10	1610	83	45	83
5/11	1602	91	40	87
5/13	1605	90	36	80
5/16	1613	88	34	82
5/17	1610	82	32	62
5/18	1618	86	34	84
5/19	1630	82	38	64
5/20	1618	83	46	64
5/23	1610	92	38	87
5/24	1610	92	46	92
5/25	1612	98	47	83
5/26	1609	97	53	86
5/27	1612	100	52	88
6/1	1610	90	45	88
6/2	1620	90	64	88
6/3	1622	93	46	90
6/6	1604	98	42	88
6/7	1616	92	50	90

Temperatures were recorded from a maximum/minimum thermometer located on the north end of the shadehouse. The thermometer was not set up according to Weather Service specifications. The 50% shade provided by the shadehouse did not prevent the thermometer from being exposed to direct sunlight, therefore, the day time highs are "sun" temperatures. The low temperatures may be considered representative.

One value of the temperature recordings is to demonstrate the temperature extremes the seedlings in the shadehouse experienced. Recordings were stopped on June 7 because a freeze was no longer considered a possibility and the purpose of recording temperatures was to document any freeze that occurred.

Table 4 records the maximum, minimum, mean, mode, and median for height and caliper in inches from two baskets of seedlings from the crop sown in February 1983 and moved to the shadehouse May 3, 1983. The measurements were taken on August 1, 1983.

Table 4.--Measurements of seedlings removed from the greenhouse 5/3/83 as of 8/1/83.

Basket	Caliper (inches)				
No.	Max.	Min.	Mean	Mode	Median
1	3/8	1/16	0.157	1/8	5/32
2	7/32	3/32	0.144	1/8	1/8

Basket	Height (inches)				
No.	Max.	Min.	Mean	Mode	Median
1	7	2 1/2	4.865	5.25	4.75
2	6 7/8	2	4.03	4	4

Basket number 1 contained 52 seedlings and basket number 2 contained 50. The maximum possible number of seedlings per basket was 52.

The seedlings removed in May are shorter and have much woodier stems than those removed from the greenhouse in June.

The seedlings in the shadehouse were watered Monday and Thursday mornings and fertilized with 2 lbs. 9-45-15+STEM/6 qts. water through the shadehouse lines along with the rest of the shadehouse seedlings. These seedlings were moved back into the greenhouse on May 23, 1983, for flushing and stressed in the shadehouse. The Monday and Thursday watering 9-45-15 fertilizer was reinstated after stressing.

Table 5 records the maximum, minimum, mean, mode, and median of baskets from the crop sown in early February 1983, and moved to the shadehouse on June 7, 1983.

Table 5.--Measurements of seedlings removed from the greenhouse 6/7/83 as of 8/1/83

Basket	Caliper (inches)				
No.	Max.	Min.	Mean	Mode	Median
1	3/32	1/16	0.119	1/8	1/8
2	5/32	3/32	0.124	1/8	1/8

Basket	Height (inches)				
No.	Max.	Min.	Mean	Mode	Median
1	7	3	4.954	4	5 1/4
2	7	2	5.02	4 1/2	5

Basket number 1 contained 52 seedlings and basket number 2 contained 52. The maximum possible was 52 seedlings.

CONCLUSIONS

Initial results indicate the potential for four crops of containerized ponderosa pine tree seedlings annually at the BIA greenhouse facility in Albuquerque, N.M. The smaller seedlings should survive the harsh planting sites in New Mexico, but only a survival study can determine this field survival and growth is the bottom line One month, early May to early June, growth in a greenhouse with subsequent shadehouse growth appears to be enough to produce a seedling that will overwinter in a shadehouse in Albuquerque, N.M. During an on-site inspection by Dr. Richard W. Tinus on July 20, 1983, he stated that these conclusions at that time seemed to be valid.

The purpose of this paper is to indicate the possibility of increasing crop production from three to four crops annually at the BIA greenhouse in Albuquerque, N.M. The problems of an administrative study in a production greenhouse are obvious. While all selections made were random, 2 baskets out of 1,523 may not be a large enough sample, therefore, a statistical analysis was not performed. The potential may exist, however, and therefore further research is needed.

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Contains 17 papers describing successful procedures, guidelines, and problems in propagation and production of native plants. Emphasis is on seed or plant production for revegetating disturbed lands.

KEYWORDS: native plant production, land reclamation, planting techniques, shrub adaptation, nursery practices

PESTICIDE PRECAUTIONARY STATEMENT

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

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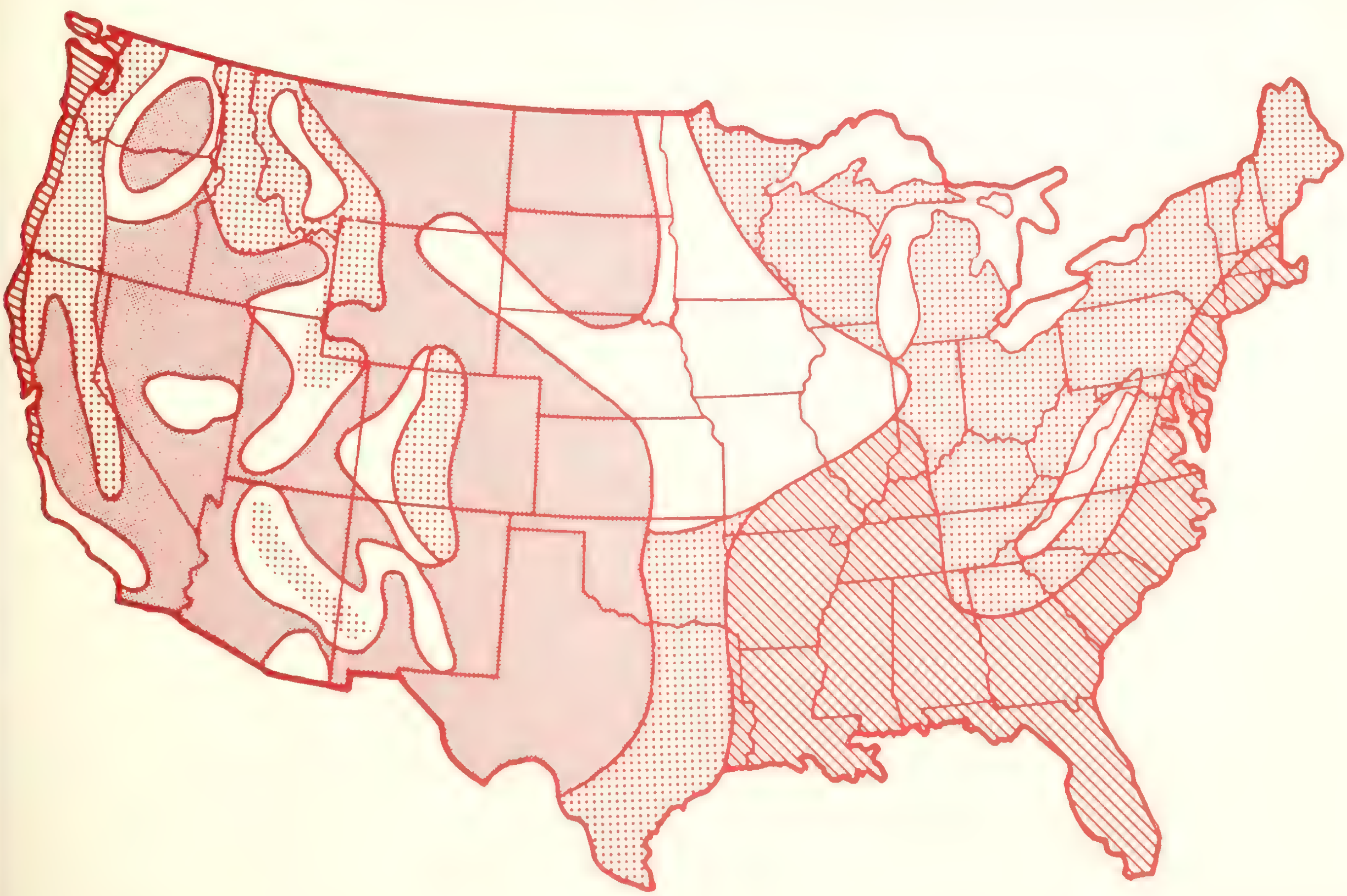
General Technical Report INT-169

July 1983

The 1978 National Fire-Danger Rating System: Technical Documentation



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JACK D. COHEN received his bachelor's degree in forest science from the University of Montana in 1973 and his master's degree in bioclimatology from Colorado State University in 1976. He did environmental air quality research before joining the National Fire-Danger Rating System research work unit at the Northern Forest Fire Laboratory, Missoula, Mont., in May 1976. In 1979 he transferred to the Forest Fire Meteorology Project at the Pacific Southwest Forest and Range Experiment Station in Riverside, Calif. He has since joined the Prescribed Fire Project at Riverside.

RESEARCH SUMMARY

The National Fire-Danger Rating System (NFDRS), implemented in 1972, was revised during a 3-year project (1975 to 1978) and reissued as the 1978 NFDRS. This report describes the developmental history of the NFDRS and its technical foundation.

Detailed information is provided on modeling forest fuels and fuel moisture, and on development of the NFDRS components and indexes. The report presents equations used in the 1978 NFDRS and an extensive bibliography.

CONTENTS

The 1978 National Fire-Danger Rating System: Technical Documentation

Compilers:
Larry S. Bradshaw
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Jack D. Cohen

HISTORY AND BACKGROUND

Fire control conferences called by the Forest Service, U.S. Department of Agriculture, in Ogden, Utah, in 1940 and 1954 highlighted the need for a uniform fire-danger rating system that could be applied nationwide. Conference committees recommended that the system focus on the environmental factors controlling the moisture content of fuels.

In 1954, several different fire-danger rating systems were in use across the Nation. Improved communications and transportation, however, were making possible mutual assistance agreements among fire control organizations. State compacts and agreements among Federal agencies and regions brought together fire control teams from widely dispersed sections of the country. A uniform system of rating fire danger and fire behavior was therefore essential for efficient communication among all those concerned with wildland fires.

In 1958, a committee of Forest Service fire research and wildfire control personnel decided that development of a national fire-danger rating system was feasible. In June, the Washington Office Division of Fire Research organized a team headed by John Keetch, Washington Office, Aviation and Fire Management, to formulate and develop the system. Full-time work began a year later.

By 1961, the basic structure of a four-phase fire-danger rating system had been outlined, but only the first phase, fire spread, was ready for field testing. The spread phase provided two indexes to predict the relative forward spread of a fire—one for fires burning in a comparatively closed environment under a timber canopy (timber spread index), and the other for fires burning in open areas of fine fuels. A third number, the buildup index (BUI), was designed to indicate the cumulative drying of the heavier fuels. The BUI was used in the computation of the timber spread index. Following field testing in 1962 and 1963, the Forest Service issued a handbook in 1964 (FSH 5109.11) covering the spread phase of the planned development. By the next year, most fire control organizations in the United States were using at least a modified version of the spread index.

The regional adaptations that quickly followed indicated that the spread index was not uniformly applicable across the country. Furthermore, because the remaining phases—ignition, risk, and fuel energy—were not available, many fire control agencies failed to adopt the new system, preferring instead to continue using in-place fire-danger methods. The Keetch project was closed before these three phases were developed.

In 1965, a research unit at Seattle, Wash., led by Donald F. Flora, took a new look at the needs and requirements of a national system. A research forester working for Flora, James E. Hefner, surveyed fire control agencies throughout the country, analyzed their requirements, and recommended that research leading to the completion of the National Fire-Danger Rating System be resumed.

In 1968, the Forest Service established the National Fire-Danger Rating System research work unit at Fort Collins, Colo. (appendix A). Led by research meteorologist Mark J. Schroeder, the unit formulated the following goals:

1. A 1972 target date was set to complete development of the system for field use. Fire researchers agreed that a fire-danger rating system superior to any currently in use could be developed from knowledge at hand; it was not necessary to wait until all pertinent research was completed.

2. The system would be structured to enable information such as better prediction equations and improved fuel models to be readily incorporated. Such refinements would take the form of updated computer programs or new tables supplied to users; the basic format and definitions were to remain unchanged.

3. The system would be introduced as a complete, comprehensive package, not index by index.

4. The complete system would include a subjective evaluation of "risk." The development of an objective method would be deferred until the physics of fuel moisture relationships and fire behavior had been developed sufficiently to meet the needs of the system.

5. Ultimately, the system would be purely analytical, based on the physics of moisture exchange, heat transfer, and other known aspects of the problem. Although laboratory and field checks would be made and experimentation needed to establish basic relationships, the fire behavior based aspect of the system would not be based on empirical studies or statistics.

6. The system would be evaluated and updated by 1978.

In 1970, a preliminary version of the system was tested in Arizona, New Mexico, and Georgia. Eight National Forests, one Bureau of Land Management (BLM) district, two National Park Service (NPS) units, and the Georgia Forestry Commission participated (see appendix A). In 1971, an improved version was tested in the Southwest. The Forest Service, BLM, NPS, Bureau of Indian Affairs (BIA), and State agencies conducted field trials at nearly 150 locations in the continental United States and Alaska.

The 1972 National Fire-Danger Rating System (NFDRS) (fig. 1) provided three fire behavior components and three indexes for rating fire danger. It had five fuel classes (three dead, two live), nine fuel models, and three slope classes. Live fuel moisture was estimated by measuring the ratio of green material to total "fine" plant material in ten 1-foot-diameter ground samples along a 300-foot transect (Fosberg and Schroeder 1971). Separate but crude risk factors for both man-caused and lightning-caused fires were provided. These were combined with a single ignition component to provide an occurrence index (a number related to the potential fire incidence within a rating area). All of the components and indexes of the 1972 NFDRS were normalized on a scale of 0 to 100.

Forest Service Research Paper RM-84 (Deeming and others 1972, revised 1974) was the summary publication of the development effort. RM-84 was written for the field user and contained complete instructions for computation and application of the components and indexes for its nine fuel models. It was nontechnical and qualitative, but a technical development paper was prepared as an office report (Schroeder and others 1973). Much of the material here is from that report.

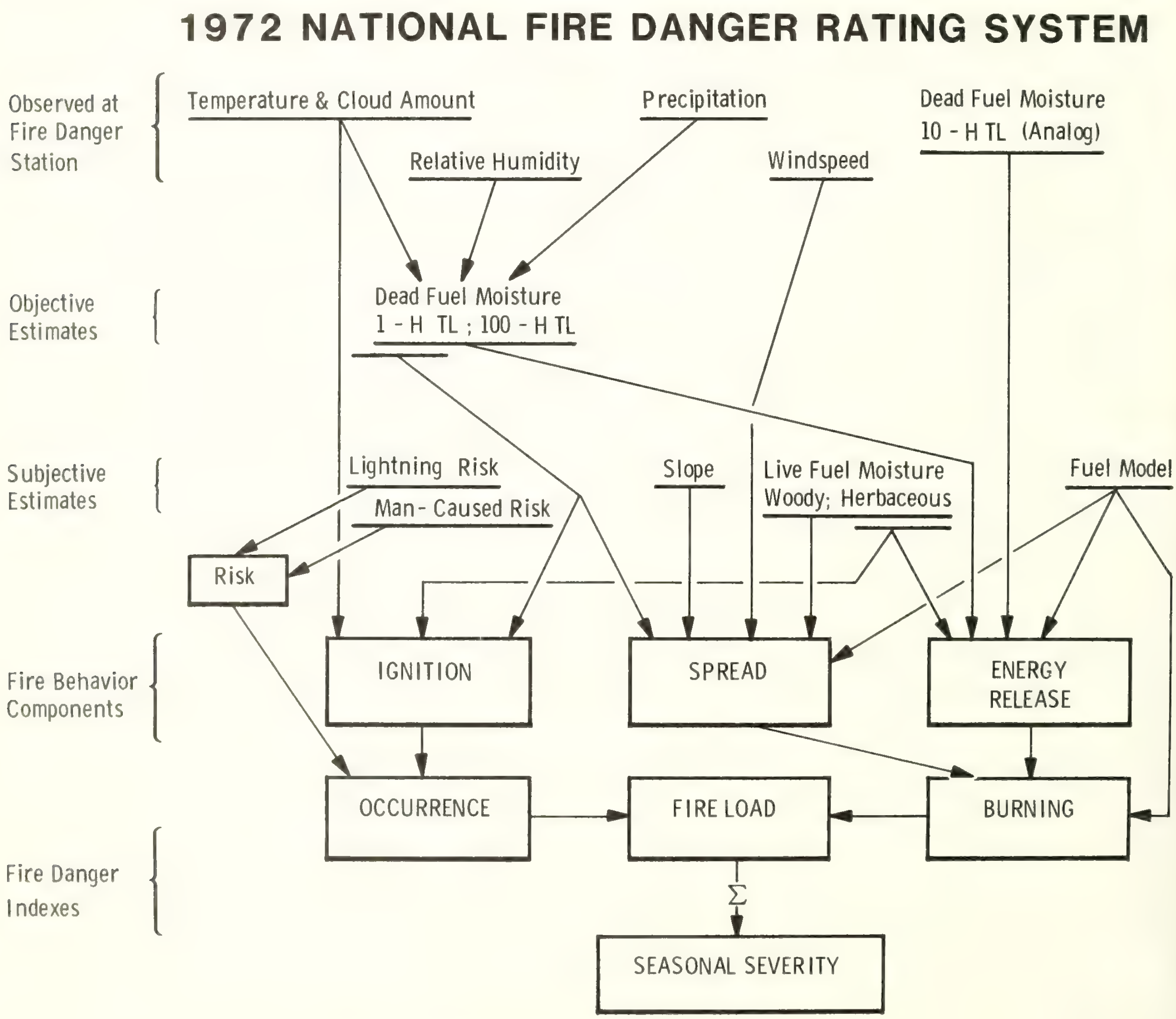

Figure 1.—Structure of the 1972 National Fire-Danger Rating System (from Deeming and others 1972, revised 1974, p. 3).

In 1973, the computer program FIRDAT (Furman and Helfman 1973) was made available at the U.S. Department of Agriculture's Fort Collins Computer Center (FCCC) to process historical fire-weather data through the NFDRS algorithms. In 1975, the National Fire-Weather Data Library (NFWDL) for archival and retrieval of fire-weather data was developed and installed at FCCC (Furman and Brink 1975). FIRDAT and the NFWDL provided a systematic means of developing fire-weather and fire-danger climatologies, which are critically important for fire management planning.

The same year, after 4 years of development and testing, the entire fire-danger rating process was computerized in the AFFIRMS processor (Helfman and others 1975, revised 1980). AFFIRMS, an interactive time-share program, computes fire-danger ratings from daily fire-weather observations and forecasts and creates fire-weather data tapes that are incorporated into the NFWDL at FCCC.

By the summer of 1976, data from more than 800 fire-weather stations across the United States were being processed through AFFIRMS, and the system indexes and components were being calculated manually each day for some 400 stations. By the spring of 1977, all Federal agencies and 35 State agencies charged with forest and rangeland fire protection responsibilities were using the 1972 version of the National Fire-Danger Rating System.

Responsibility for the 1978 NFDRS update was given to John E. Deeming who had joined the NFDRS project at Fort Collins, Colo., in 1970. The project was relocated to the Intermountain Forest and Range Experiment Station, Northern Forest Fire Laboratory, Missoula, Mont., during the summer of 1975. Deeming was joined that summer by Robert E. Burgan and the following spring by Jack D. Cohen, both research foresters. The 1978 update reflects changes made possible by feedback from 1972 system users and advances in fire science and fuels technology.

The 1978 National Fire-Danger Rating System update addressed several major problems identified in the 1972 system:

Response to drought.—The 1978 update has improved response to short-term drought, with the addition of a 1,000-hour timelag dead fuel class, and the inclusion of live fuels in all but the slash fuel models. Live fuel moisture models emulate plant moisture response to phenological cycles, replacing the fuel moisture transects used in the 1972 NFDRS.

Seasonal sensitivity.—Calculation of fuel moisture for the 100-hour and 1,000-hour timelag fuels was altered to account for a day's drying power as affected by day length. Day length is calculated from the date and a fire-weather station's latitude.

Component sensitivity.—The 1972 system had its components and indexes normalized to a 0 to 100 scale, which often caused moderate fire climates to never see a rating greater than 10. The spread and energy release components, and the burning index now have open-ended scales that yield a threefold to fivefold increase in sensitivity.

Occurrence indexes.—The 1978 NFDRS has separate occurrence indexes for man-caused and lightning-caused fires (the 1972 system had only one occurrence index for both types of fires). The occurrence index models in the 1978 update reflect major improvements over the simplistic model used in the 1972 system.

Ignition component.—The 1978 NFDRS ignition component is a function of the probability of ignition and spread component. The 1972 system's ignition component was simply the probability of ignition.

More fuel models.—The 1978 NFDRS offers 20 fuel models to describe a fuel situation; the 1972 system had 9.

Better slope definition.—The 1978 NFDRS has five slope classes to describe an area's topography; the 1972 system had three. Two slope classes were added to cover steep terrain (greater than 50 percent slope).

Live fuel moisture models.—The 1978 NFDRS introduced models for computing the fuel moisture of live herbaceous and shrub fuels. The model also causes herbaceous material, when cured, to be transferred to the 1-hour dead fuel loading class to better emulate actual fire danger prior to spring green-up and after autumn curing.

A summary publication (Deeming and others 1977) describes the 1978 NFDRS and, for NFDRS users not on the AFFIRMS network, there is a manual version of the 1978 system (Burgan and others 1977). The 1978 National Fire-Danger Rating System is now being used by most Federal, State, and private agencies charged with wildland fire protection. The 1978 changes have been included in new releases of FIRDAT and AFFIRMS (Main and others 1982; Helfman and others 1975, revised 1980).

PHILOSOPHY

The development and application of both the 1972 and 1978 NFDRS's are grounded in six major principles:

1. The system would consider only the "initiating fire." This is defined as a fire that is not behaving erratically; it is spreading without spotting through fuels that are continuous with the ground (no crowning). The "state of the art" does not yet extend to fires that exhibit erratic behavior other than to show that extreme behavior is correlated with increasing fire danger.

2. The system would provide a measure of that portion of the potential job of containment that is attributable to fire behavior. The concept of containment as opposed to extinguishment is essential because it limits the fire behavior prediction to the head of the fire. Those portions of the containment job dealing with accessibility, soil condition, and resistance to line construction must still be evaluated by other means.

3. The length of the flames at the head of the fire was assumed to be directly related to the contribution of fire behavior to the containment job.

4. The system would attempt to evaluate the "worst" conditions on a rating area by using meteorological measurements taken (a) when fire danger is normally the highest (usually in the early afternoon), (b) at sites in the open, and (c) where possible, at sites on drier (southerly

or westerly) exposures. This means that extrapolation of fire-danger values to areas other than those immediately in the vicinity of the fire-danger station would involve scaling down, not up.

5. The system would provide ratings that would be physically interpretable in terms of fire occurrence and behavior. These evaluations could then be used alone or in combinations, giving the user the flexibility needed to deal with the entire spectrum of fire control planning problems.

6. Ratings would be relative, not absolute. The ratings would be linearly related to the particular aspect of fire danger being evaluated. This means that when a component or index doubles, a doubling of the rated activity relative to what has previously been observed should be anticipated. Because of the many variables in the computations, the low spatial and temporal resolution of fuels and weather data, and incomplete understanding of some relationships, fire danger can only be broadly defined within a rating area.

STRUCTURE

The 1978 NFDRS (fig. 2) provides four indexes to facilitate the planning of fire control activities: the man-caused fire occurrence index (MCOI); the lightning-caused fire occurrence index (LOI); the burning index (BI); and the fire load index (FLI).

The MCOI is derived from man-caused risk (R_{MC}), an assessment of man-caused fire sources in the rating area, and the ignition component (IC), the likelihood that a firebrand will cause a reportable fire.

The lightning-caused fire occurrence index (LOI), similar in concept to the MCOI, is derived from the ignition component (IC) and lightning risk (R_L), an indicator of thunderstorm and lightning activity. After being scaled to an area's experience, both the MCOI and LOI can be used to predict, on the average, the total expected number of reportable fires that will occur on a rating area.

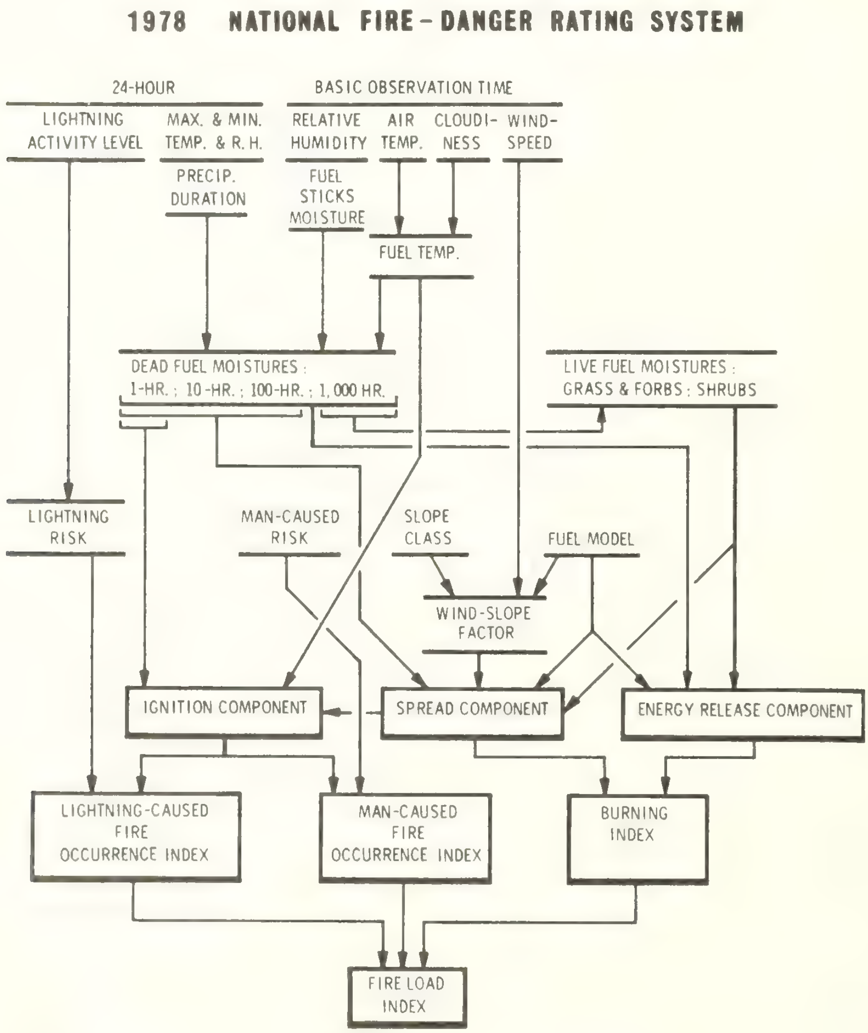

Figure 2.—Structure of the 1978 National Fire-Danger Rating System (from Deeming and others 1977, p. 6).

The burning index is derived from the spread component (SC), a relative index of rate of fire spread, and the energy release component (ERC), a relative index of the amount of heat released per unit area in the flaming zone of an initiating fire. Considered together, they indicate the difficulty of containment. The combined index, BI, is linearly related to the length of flames at the head of the fire.

The difficulty of containing a single fire (the BI) and the expected number of fires projected by the MCOI and LOI combine to produce the fire load index (FLI), a measurement of the total fire containment job. The FLI is the NFDRS cumulative index, integrating risk, ignition probability, and fire behavior potential.

The risk ratings (R_{MC} and R_L), man-caused fire occurrence index (MCOI), lightning-caused fire occurrence index (LOI), ignition component (IC), and fire load index (FLI) are expressed on a scale of 0 to 100. The scales of the spread component (SC), energy release component (ERC), and burning index (BI), are open ended.

Eleven elements of a fire-weather observation drive the various models that make up the National Fire-Danger Rating System. Observation time (early to midafternoon) elements are:

1. Temperature, °F,
2. Relative humidity, percent,
3. State of the weather,
4. Ten-minute average 20-ft windspeed (mi/h), and
5. Fuel stick moisture, percent.

Elements for the 24-hour period ending at the observation time are:

6. Duration of precipitation, hours,
7. Amount of precipitation, inches,
8. Maximum 24-hour temperature, °F,
9. Minimum 24-hour temperature, °F,
10. Maximum 24-hour relative humidity, percent, and
11. Minimum 24-hour relative humidity, percent.

NOTE: AFFIRMS will also accept metric environmental inputs.

Dead fuels are stratified by moisture response timelag classes (1, 10, 100, and 1,000 hours); live fuels by type of vegetation (grass-forbs or woody shrubs). Fuel classifications are discussed in the section titled "Classification of Fuel Components," under "Forest Fuels"; fuel moisture calculations are covered in sections titled "Dead Fuel Moisture Models" and "Live Fuel Moisture Models." Precipitation duration affects fuel moisture more significantly than does precipitation amount. The 24-hour precipitation amount is recorded because it is a standard climatological element.

The traditional fuel moisture sticks are used as an analog of the 10-hour timelag fuel class. A set of sticks is an array of three 1/2- by 18-inch ponderosa pine dowels. The ovendry weight of fuel sticks decreases with extended weathering, so a correction for age is applied.

Fuel particle and fuel bed property values are quantified in the system's 20 stylized fuel models. Fuel models consist of fuels information required for input to the system's SC and ERC models. A fuel model contains fuel characteristic values typical of fuel descriptions for a general cover type.

Wind, slope, fuel moistures, and fuel descriptors (via fuel models) are required to compute the SC and ERC using a modification of the Rothermel (1972) fire spread model (see section titled "Fire Behavior Model"). The burning index computations are based on Byram's flame length model (Byram 1959). The specifics of the 1978 NFDRS indexes and components SC, ERC, BI, IC, MCOI, LOI, and FLI are discussed in sections titled "Fire Behavior Components," "Ignition Component, Risk, and Occurrence Indexes," and "The Fire Load Index."

FOREST FUELS

The delineation of wildland fuel characteristics for fire behavior modeling and resultant fire-danger rating is based on quantitative descriptions of fuel particle and fuel bed properties. The important fuel particle properties are size, density, chemical composition, and shape (a cylindrical shape is assumed). Important fuel bed characteristics are fuel amounts (dry weight load by size class, lb/ft^2) and fuel bed depth. (The fuel bed is assumed to be uniform and continuous, and the various fuel classes uniformly distributed throughout the fuel bed.) Stylized fuel models are discussed in the section titled "Fuel Models."

Classification of Fuel Components

DEAD FUELS

Dead fuels are fuels in which the moisture content is exclusively controlled by environmental conditions—temperature, radiation, relative humidity, and precipitation.

The relationships among environmental conditions and dead fuel moisture in the 1978 NFDRS draw heavily upon definitions and theory proposed by Byram (1963) and expanded on by Fosberg (1970). Byram demonstrated that the moisture content of dead fuels drying under constant conditions follows an exponential decay curve. He defined the timelag interval, τ, as the time required for fuels to lose approximately two-thirds of their initial moisture content (the actual amount is $1-1/e$, where e is the base of natural logarithms).

Byram defined the relative moisture content, μ, as:

$$\mu = \mu_o \cdot \exp(-\tau T) \qquad (\%) \qquad (1)$$

where

T is the period of environmental stress (h),
τ is the fuel particle timelag (h), and
μ_o is the initial moisture content of the fuel particle (%).

The relative moisture content (%) may also be defined:

$$\mu = (EMC - \bar{\mu})/(\mu_o - \bar{\mu}) \qquad (2)$$

where

$\bar{\mu}$ is the mean moisture content (%) over the time period,
EMC is the equilibrium moisture content (%), and
μ_o is the initial moisture content (%) at the onset of the stress period.

Equilibrium moisture content (EMC) is the moisture content dead fuels would obtain if left in a steady-state environment long enough to obtain equilibrium (no net moisture exchange). It is computed using the fuel-atmosphere interface dry bulb temperature and relative

humidity. Computation of EMC values is discussed further in the section titled "The 1-Hour Timelag Fuel Moisture Models," and appendix C.

Fosberg (1970) then introduced similarity theory expressed by a Fourier number (F_O). Using both experimental and theoretical methods, Fosberg and others (1970) showed the Fourier number to be a universal constant for fuel moisture. For cylindrical fuels, the Fourier number is

$$F_o = (\tau\nu)/r^2 \tag{3}$$

and for the general case

$$F_o = (\tau\nu\sigma^2)/(4\chi_s^2) \tag{4}$$

where

τ is the particle's moisture timelag (h),

ν is the characteristic moisture diffusivity of the fuel particle (cm^2/min),

r is the fuel particle radius (cm),

σ is the particle's surface area-to-volume ratio (see section titled "Fuel Particle Properties"), and

χ_s is a fuel particle shape factor (not used in the NFDRS).

In both cases, $F_o = 0.18$.

Experimentally determined, diffusivity inherently contains information on the species, and thus automatically accounts for the presence of waxes and resins that hinder fuel moisture transport. Some typical values of ν are given in table 1 for selected species.

Fosberg (1971b) then used the Fourier number to solve for a characteristic timelag similarity coefficient (ζ), and defined the change of moisture content for transient surface conditions as:

$$\delta\mu/\Delta\mu = 1 - \zeta \cdot e^{(-T.\tau)} \tag{5}$$

where

$\delta\mu$ is the actual moisture content change (%) in the stress period (T, h),

$\Delta\mu$ is the potential moisture content change (%) in the stress period (T),

ζ is the similarity coefficient (dimensionless),

e is the base of the natural logrithms, and

τ is the fuel particle timelag (h).

$\Delta\mu$ may be estimated from the difference in the EMC at the beginning and end of the stress period as calculated from the initial and ending fuel-atmosphere temperatures and relative humidities. This equation provides the basis for theoretical calculation of dead fuel moisture.

The range of moisture contents over different time intervals is characteristic of fuel particle size. Figure 3 illustrates a normal diurnal cycle in which the moisture content of fine fuels vary widely. Intermediate-sized fuels vary within a narrower range, and large fuels within a very limited range (Gisborne 1928; Brackebusch 1975).

Using equation 5, Fosberg (1971a) simulated the magnitude of the range of moisture responses of fuels with different timelags to weather cycles of 1-day (diurnal), 4-day (synoptic), 30-day (planetary), and 1-year (annual). He used climatological data from 10 locations to represent the diurnal variation of boundary value moisture content and data from 2 locations to represent the annual variations of boundary moisture content.

Table 1.—Typical diffusivity values for selected forest fuels (from unpublished 1972 NFDRS documentation)

Fuel type	Diffusivity
	cm²/s
Ponderosa pine dowel (*Pinus ponderosa*)	
0.159 cm radius	8.32 X 10-
0.318 cm radius	8.32 X 10-
0.635 cm radius	8.32 X 10-
1.0 cm radius	8.32 X 10-
1.27 cm radius	8.32 X 10-
2.54 cm radius	8.32 X 10-
5.08 cm radius	8.32 X 10-
Douglas-fir dowel (*Pseudotsuga menziesii*)	
1.0 cm radius	8.30 X 10-
Lodgepole pine dowel (*Pinus contorta*)	
1.0 cm radius	8.42 X 10-
Alaska cedar dowel (*Chamaecyparis nootkatensis*)	
1.0 cm radius	5.94 X 10-
Eastern white pine dowel (*Pinus strobus*)	
1.0 cm radius	10.3 X 10-
Ponderosa pine needles (*Pinus ponderosa*)	2.0 X 10-
Western white pine needles (*Pinus monticola*)	1.18 X 10-
Eucalyptus leaves (*Eucalyptus obliqua*)	4.77 X 10-
Quaking aspen leaves (*Populus tremuloides*)	—
Cheatgrass (*Bromus tectorum*)	
Leaves	—
Stalks	—
Plant	2.58 X 10-
Fescue (*Festuca idahoensis*)	
Leaves	—
Stalks	—
Plants	—

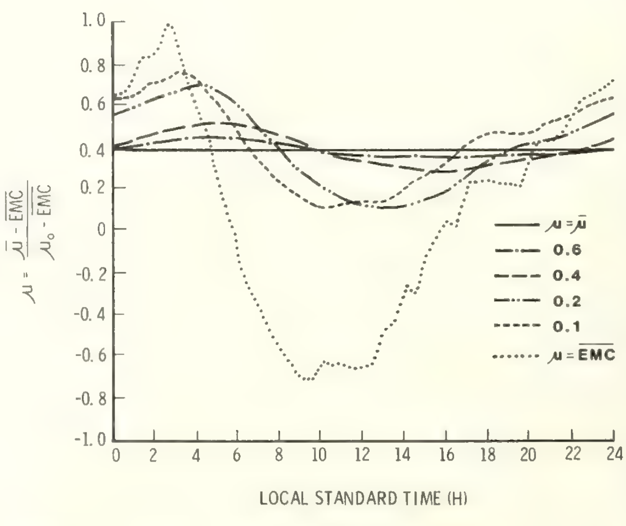

Figure 3.—Diurnal variations of relative moisture content (m) for fuels of increasing radii (adapted from Fosberg 1971a, p. 68).

Figure 4 shows the relative ranges of moisture content ($\Delta\mu$) plotted over timelag (τ) for the four timelag periods.

The range of moisture content in each case period is

$$\Delta\mu = (\mu_{max} - \mu_{min}) \tag{6}$$

where

μ_{max} is the period maximum moisture content (%), and
μ_{min} is the period minimum moisture content (%).

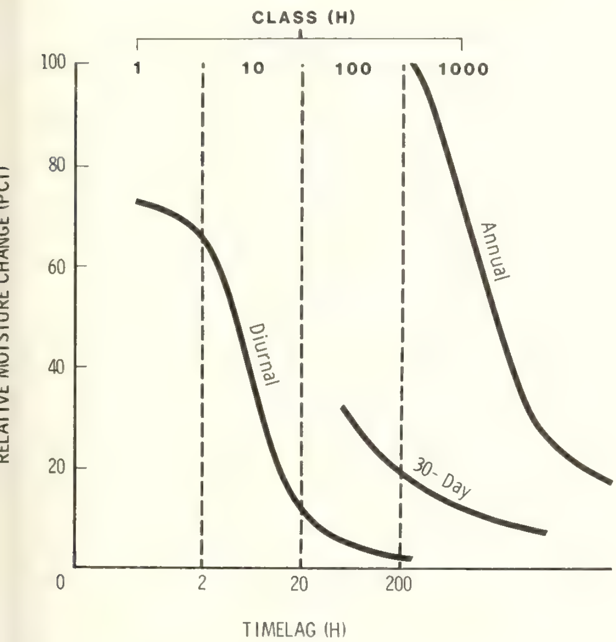

Figure 4.—Moisture recovery curves for fuel particles of increasing radii (adapted from unpublished 1972 NFDRS documentation).

The $\Delta\mu$'s for a given time period characterize fuel particles of a given timelag. As τ increases, $\Delta\mu$ decreases if the period is constant. As time periods increase, fuel particles with a constant τ exhibit a larger $\Delta\mu$.

This relationship provided a basis for dead fuels classification (Lancaster 1970). The recovery curves, all having a reverse S-shape, are characterized by three straight-line segments. For the diurnal cycle, fuels with a timelag less than 2 hours show a high recovery; those with timelags greater than 20 hours show a low recovery. Fuels with timelags less than 200 hours show an intermediate recovery range for the 30-day cycle and a high recovery range for the annual cycle.

Based upon these differences, four groupings of timelags were delineated: fuels with timelags up to 2 hours; from 2 to 20 hours; from 20 to 200 hours; and more than 200 hours. Each group responds uniquely to successively longer cycles. The approximate midpoints of these timelag ranges are used as the basis for a classification scheme: 1-hour, 10-hour, 100-hour, and 1,000-hour timelag fuels.

Exposed mosses, lichens, and cured grasses and herbs have timelags of 1 hour or less. The uppermost layer of weathered conifer needles on a forest floor typically respond to environmental stress within 2 hours, as do dead twigs of woody plants up to ¼-inch diameter. Fresh conifer needles exhibit timelags ranging from 1 to 10 hours, but approach 1 hour as waxes and resins are leached away (Van Wagner 1969; Anderson and others 1978).

The 10-hour class includes dead twigs and branches from one-fourth inch to 1 inch in diameter. Dead branchwood in the 1- to 3-inch diameter class falls into the 100-hour timelag group, and dead logs and branchwood from 3 to 8 inches constitute the 1,000-hour timelag class. The dead fuel moisture models for each size class of dead fuel are presented in the section titled "Dead Fuel Moisture Models," with subsections on the 1-hour, 10-hour, 100-hour, and 1,000-hour timelag fuel moisture models.

LIVE FUELS

In living fuels moisture content is controlled by the physiological processes of the plant. Changes in moisture of the two classes of live fuels considered by the 1978 NFDRS are both seasonal and short term. These classes are herbaceous plants (grasses and forbs) and woody shrubs. Dynamic live fuel moisture models have been developed to simulate the greening and curing process of these fuels through a growing season and also short-term moisture content fluctuations due to extreme environmental conditions. The live fuel moisture models are discussed in the section titled "Live Fuel Moisture Model."

Herbaceous Plants

Plants that do not develop persistent woody tissues such as grasses, forbs, and ferns make up the NFDRS herbaceous fuel class. The herbaceous class is further subdivided into annual and perennial types. When the fuel moisture falls below 30 percent, these plants are considered cured and the moisture content defaults to that of the 1-hour timelag fuels. The herbaceous fuel moisture model is presented in the section titled "Herbaceous Fuel Moisture."

Woody Shrubs

The second category of live fuel in the 1978 NFDRS is the perennial woody shrub. These fuels are considered dormant when the moisture content falls to 50 percent. Above this value these plants are allowed a maximum moisture content of 250 percent during the growing season. The woody shrub fuel moisture model does not allow the estimated shrub moisture content to fall so low that the shrubs would have to be considered dead. But at the low end of their moisture range they are considered dormant. The woody fuel moisture model is presented in the section titled "Woody Fuel Moisture Model."

Fuel Particle Properties

The physical and chemical fuel particle properties described in this section were originally defined by Rothermel (1972). These properties and fuel moisture response to environmental stress (via fuel size) are fundamental to rating fire danger. Physical characteristics such as fuel particle size and shape affect the ease of ignition and rate of moisture exchange with the environment. The energy potentially available through combustion is a chemical property.

PHYSICAL PROPERTIES

Fuel Particle Surface Area-to-Volume Ratio (σ)

The gain and loss of heat and moisture and the evolution of combustible gases occur through the surface of a fuel particle and occur at rates directly related to the amount of surface area per unit volume of the particle. Thus the surface area-to-volume ratio (σ) of a fuel particle is a very important fuel particle property. Fuel particles with large σ's will ignite more readily than those with relatively small σ's. For a cylinder, the surface area-to-volume ratio is inversely related to the radius.

The surface area (neglecting end area) of a cylinder, A, is

$$A = 2\pi rL \quad (\mathrm{ft}^2) \tag{7}$$

and its volume

$$V = \pi r^2 L \quad (\mathrm{ft}^3) \tag{8}$$

where r is the radius and L is the length. The surface area-to-volume ratio for cylindrical fuels is

$$\sigma = A/V = (2\pi rL)/(\pi Lr^2) = 2/r \quad (1/\mathrm{ft}). \tag{9}$$

Fuel Particle Density (ϱ_p)

The next important fuel particle property is the density, ϱ_p. This is needed to determine the packing ratio, β (see section titled "Fuel Compactness"), of a fuel bed. A ϱ_p value of 32 lb/ft^3 is used for both live and dead fuels in all of the fuel models.

Table 2 contains typical values of σ and ϱ_p for selected fuel particles.

Table 2.—Typical fuel particle properties of selected forest fuels (from unpublished 1972 NFDRS documentation)

Fuel Type	Shape Factor (ψ)	Surface area vol ratio (σ, cm^{-1})	Cross sectional area (A, cm^2)	Particle density (ϱ, g/cm^3)	Timelag (τ, h)
Ponderosa pine dowel					
Pinus ponderosa					
0.159 cm radius	1	12.6	0.079	0.418	1.5
.318 cm radius	1	6.3	.317	.418	6.1
.635 cm radius	1	3.15	1.27	.418	24.0
1.0 cm radius	1	2.0	3.14	.418	59.0
1.27 cm radius	1	1.57	5.07	.418	97.0
2.54 cm radius	1	.787	20.3	.418	388.0
5.08 cm radius	1	.394	81.1	.418	1,551.0
Douglas-fir dowel					
Pseudotsuga menziesii					
1.0 cm radius	1	2.0	3.14	.508	59.0
Lodgepole pine dowel					
Pinus contorta					
1.0 cm radius	1	2.0	3.14	.432	59.0
Alaska cedar dowel					
Chamaecyparis nootkatensis					
1.0 cm radius	1	2.0	3.14	.458	82.0
Eastern white pine dowel					
Pinus strobus					
1.0 cm radius	1	2.0	3.14	.362	47.8
Ponderosa pine needles					
Pinus ponderosa	1.3	57.6	6.5X10^{-4}	—	3.91
Western white pine needles					
Pinus monticola	1.3	90.5	2.6X10^{-4}	—	2.7
Eucalyptus leaves					
Eucalyptus obliqua	1.43	61.8	6.8X10^{-4}	—	1.57
Quaking aspen leaves					
Populus tremuloides	1.07	139.8	7.5X10^{-5}	—	—
Cheatgrass					
Bromus tectorum					
Leaves	1.9	189.0	1.3X10^{-4}	—	—
Stalks	—	75.8	—	—	—
Plant	—	145.0	—	—	.07
Fescue					
Festuca idahoensis					
Leaves	2.2	190.0	1.7X10^{-4}	—	—
Stalks	—	68.6	—	—	—
Plant	—	182.0	—	—	—

CHEMICAL PROPERTIES

Fuel particles have three chemical properties that affect combustion and hence must be considered by fire-danger rating: heat content, total mineral content, and effective mineral content.

Heat Content (H)

The energy available per unit mass of fuel through combustion is called the heat content. In woody fuels, on a dry weight basis, it is relatively consistent from one plant species to another. Heat content may also be referred to as the heat of combustion. In the NFDRS, this value ranges from 8,000 Btu/lb to 9,500 Btu/lb and varies by fuel model. Table 3 summarizes some typical values for western fuels.

Total Mineral Content (S_t)

Total mineral content (S_t) is the fraction of a fuel mass composed of inorganic minerals. The inorganic mineral content reduces the combustible fuel mass because only the organic portion of a fuel supports combustion. The total mineral content may also be referred to as total ash content. A value of 5.55 percent is used for both dead and live fuels in all NFDRS fuel models.

Effective Mineral Content (S_e)

The effective (active) mineral content (S_e) affects fire behavior by interfering with the chemical processes of combustion. The presence of certain mineral salts alters the pyrolysis process and promotes the formation of char and tar at the expense of more flammable volatiles. Philpot (1968, 1970) showed that the rate of thermal degradation and the amount of volatiles produced are reduced as the silica-free ash content increases. Table 4 summarizes the total ash and silica-free ash content for selected species. A value of 1 percent is used for both dead and live fuels in the NFDRS fuel models.

Table 3.—Average heat content (heat of combustion) of selected forest fuels (from Kelsey and others 1979)

Species	Wood	Bark	Twigs	Foliage
	Btu/lb			
Western redcedar	9,700	8,669	8,708	9,630
Grand fir	8,300	9,641	8,894	9,497
Western larch	8,620	9,162	9,247	8,703
Western white pine	8,620	9,355	9,464	9,040
Engelmann spruce	8,100	9,616	9,076	8,806
Lodgepole pine	8,600	9,605	9,371	9,365
Western hemlock	8,500	9,943	8,924	9,491
Douglas-fir	9,200	10,845	9,113	9,265
Ponderosa pine	9,100	9,452	10,026	9,527
Average	8,721	9,461	9,253	9,315
Sample size	35	35	43	38

Table 4.—Mineral content of selected plant materials (adapted from Philpot 1970)

Species	Part	Mineral content: Total ash	Mineral content: Silica-free-ash
		Percent dry weight	
Cellulose[1]		0.01	0.01
Douglas-fir (*Pseudotsuga menziesii*)	Wood	.11	.11
Birch (*Botula* sp.)	Wood	.18	.18
Ponderosa pine (*Pinus ponderosa*)	Wood	.22	.22
Poplar (*Populus* sp.)	Wood	.36	.36
Cheatgrass (*Bromus tectorum*)	Leaves	5.27	1.04
Medusahead grass (*Elymus caput-medusae*)	Leaves	16.02	1.17
Ponderosa pine (*Pinus ponderosa*)	Needles	3.87	1.55
Chamise (*Adenostoma fasciculatum*)	Stems	2.19	1.75
White pine (*Pinus monticola*)	Needles	3.34	2.54
Chamise (*Adenostoma fasciculatum*)	Leaves	3.63	3.33
Aspen (*Populus tremuloides*)	Leaves	5.24	5.24
Guava (*Psidium guajava*)	Green leaves	6.08	5.58
Guava (*Psidium guajava*)	Dead leaves	6.24	5.74
Guava (*Psidium guajava*)	Leaves[2]	7.79	7.29
Saltbush (*Atriplex canescens*)	Leaves	12.89	12.29
Salt tree (*Tamarix aphylla*)	Leaves	16.59	14.53
Saltbush (*Atriplex polycarpa*)	Leaves	15.39	14.83
Saltbush (*A. lentiformis v. brewerii*)	Leaves	19.26	18.63
Saltbush (*A. nuttalli v. gardnerii*)	Leaves	26.78	23.57
Saltbush (*A. gardnerii*)	Leaves	27.07	25.27

[1]Analytical fiber pulp. Carl Schleicher and Schuel Co.
[2]Treated with herbicide (2-4-D and 2-4-5-T).

Fuel Bed Properties

Five properties of fuel beds affect combustion and fire behavior:

1. Amount or loading of fuels,
2. Compactness of fuels,
3. Continuity of fuels,
4. Uniformity of fuels, and
5. Fuel element arrangement and distribution.

Only amount and compactness, however, are allowed to vary. In this and other applications of the Rothermel (1972) fire spread model, the fuel bed is assumed to be continuous and uniform, and the elements of the different fuel classes are assumed to be thoroughly "mixed" and uniformly distributed throughout the length, width, and depth of the bed.

FUEL LOADS BY SIZE CLASS

Fuel loading expresses the mass of fuel per unit area in a fuel bed. Combined with the heat content, H (Btu/lb), the net fuel load is a factor in the amount of heat available per unit area of the fuel bed (Btu/lb × lb/ft² = Btu/ft²). The net fuel load (W_n) is the total fuel load (W_o) less the mass represented by the total mineral content (S_t) of the fuel particle. In combination with fuel bed depth (δ), it determines the fuel bed bulk density, ϱ_b:

$$\varrho_b = W_o/\delta \quad \text{(lb/ft}^3\text{)} \qquad (10)$$

where

W_o is the total dry fuel bed load (lb/ft²), and
δ is the fuel bed depth (ft).

FUEL COMPACTNESS (β,ϕ)

The compactness of a fuel bed is expressed as fuel bed porosity(ϕ), or packing ratio (β). Packing ratio is the ratio of the density of the fuel bed (ϱ_b) to the fuel particle density (ϱ_p):

$$\beta = \varrho_b/\varrho_p \quad \text{(dimensionless)} \qquad (11)$$

and the porosity is the dimensionless ratio of the fuel bed void volume to the total fuel bed volume:

$$\phi = V_v/V_b = (V_b - V_f)/V_b \quad \text{(dimensionless)} \qquad (12)$$

where

V_v is the bed void volume (empty space, ft³),
V_f is the bed fuel volume (ft³), and
V_b is the total bed volume (ft³).

ϕ, β, and ϱ_b are interrelated as follows:

$$\phi = (\varrho_p - \varrho_b)/\varrho_p, \qquad (13)$$

$$\varrho = 1 - \beta. \qquad (14)$$

MOISTURE OF EXTINCTION (m_x)

The fuel moisture content at which a fire will not propagate in a fuel bed is the moisture of extinction. In the 1972 NFDRS, 30 percent, which is close to the fiber saturation value for woody material, was used as the moisture of extinction. But Brown (1972) and Blackmarr (1972) found that moisture of extinction values vary with fuel bed compactness, fuel particle size, windspeed, and slope. They found extinction moisture contents ranging from 12 percent in grass to 40 percent in conifer litter. Current research at the Northern Forest Fire Laboratory should provide better guidelines for future use.

Lacking better information, the NFDRS makes several assumptions; the first is that live and dead fuels have different moistures of extinction, and that a specific fuel complex has a constant moisture of extinction for its dead fuel components.

Dead Fuel Moisture of Extinction (m_{xd})

The dead fuel moisture of extinction is a fuel-model-dependent value, with values ranging from 15 percent in the grass and brush models to 30 percent for the southern rough, pine, and pocosin models.

Live Fuel Moisture of Extinction (m_{xl})

A more extensive method is used for live fuels because their moisture contents are typically much greater than fiber saturation. Fosberg and Schroeder (1971) assumed that the heat produced by a burning mass of fuel and transferred to an equal mass of unburned fuel having a 30 percent moisture content is just sufficient to raise the temperature of the unburned fuel to ignition. As the moisture content of the unburned fuel nears zero percent, only a very small amount of heat is needed to raise the fuel temperature to ignition. When a linear relationship is assumed, these two points define the relationship between moisture content and effective heat energy (line A in fig. 5).

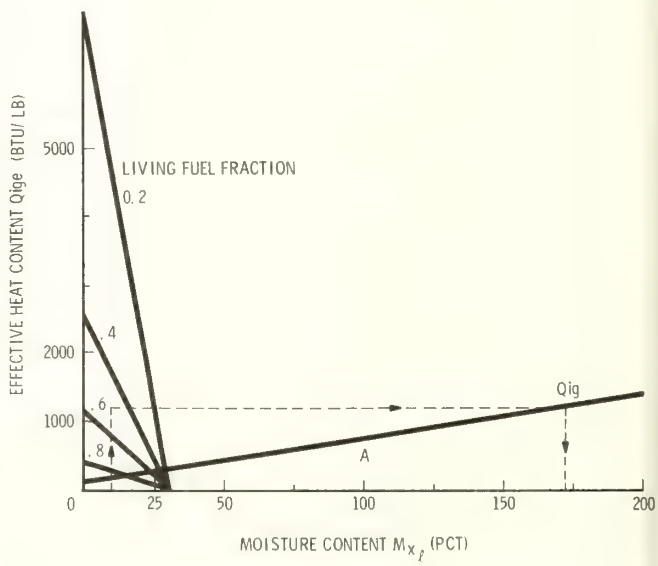

Figure 5.—Relationship between live moisture content and effective heat energy (adapted from Fosberg and Schroeder 1971, p. 3).

If the burning fuel is considered dead, and the unburned fuel live, the extinction moisture content for various proportions of live and dead fuels can be estimated over the range of dead fuel moisture content from zero to 30 percent.

Fosberg and Schroeder (1971) used the heat of preignition (Q_{ig}) per unit mass (a function of moisture content) from the Rothermel (1972) rate of spread model to estimate the effective heat energy.

In metric units:

$$Q_{ig} = 140 + 620m_f \quad (15)$$

where m_f is the 1-hour fuel moisture (fraction).

Effective heat transfer (Q_{ige}) is a function of fractional living fuel and dead fuel moisture:

$$Q_{ige} = 1{,}800((1 - \alpha)/\alpha)(1 - \frac{10}{3} m_f) \quad (16)$$

where

α is the fraction of living fuel, and

m_f is the 1-hour dead fuel moisture (fraction).

At the moisture of extinction (assumed $m_x = 0.3$), $Q_{ig} = Q_{ige}$:

$$140 + 620m_{xl} = 1{,}800((1 - \alpha)/\alpha)(1 - \frac{10}{3}m_f) \quad (17)$$

where m_{xl} is the extinction moisture content (fractional) of the unburned fuel. Solving for m_{xl}:

$$m_{xl} = 2.9((1 - \alpha)/\ \alpha)(1 - \frac{10}{3}m_f) - 0.226 \quad (18)$$

gives the m_{xl} as a fraction. It is multiplied by 100 to convert to percent.

$$m_{xl} = 290((1 - \alpha)/\ \alpha)(1 - \frac{10}{3}m_f) - 22.6. \quad (19)$$

This expression was modified by Albini (1976b) using the effective heating number concept introduced by Frandsen (1973). The heating number, a fuel load weighting factor of the form $e(-k/\sigma)$ is used to compute a dead-to-live loading ratio (W), and a weighted "fine" dead fuel moisture, m_{fw}. Albini's final expression is

$$m_{xl} = 290W(1 - m_{fw}/m_{xd}) - 22.6 \quad (20)$$

where

m_{xl} is limited to the minimum m_{xd} value,

m_{xd} is the dead fuel moisture of extinction for the fuel bed,

$$W = \frac{\sum_{j=1}^{3} \overline{W}_{n1j} \exp(-138/\overline{\sigma}_{1j})}{\sum_{j=1}^{2} \overline{W}_{n2j} \exp(-500/\overline{\sigma}_{2j})} \quad (21)$$

and

$$m_{fw} = \frac{\sum_{j=1}^{3} m_{1j}W_{1j} \exp(-138/\overline{\sigma}_{1j})}{\sum_{j=1}^{2} W_{n1j} \exp(-138/\overline{\sigma}_{1j})} \quad (22)$$

and where

W_{n1j} is the net dead fuel load (j indicates 1-hour, 10-hour, or 100-hour timelag class),

W_{n2j} is the net live fuel load (j indicates woody or herbaceous),

m_{1j} is the dead fuel moisture content (fraction),

σ_{ij} is the surface area-to-volume ratio,

$\exp(-138/\sigma_{1j})$ is the dead fuel effective heating number, and

$\exp(-500/\sigma_{2j})$ is the live fuel effective heating number.

This expression, in conjunction with the live fuel moisture model, is used for computing moisture damping coefficients for herbaceous and woody fuels in the fire model.

FUEL MODELS

The previous section described the classification of fuel particles and defined eight fuel particle and bed characteristics that are important in fire behavior modeling and resultant fire-danger rating. These eight parameters:

H.....heat content, Btu/lb
ϱ_p....fuel particle density, lb/ft^3
S_t.....total mineral content, %
S_e....effective mineral content, %
w_o....total dry fuel bed load, lb/ft^2
δ.......fuel bed depth, ft
σ,.....surface area-to-volume ratio, ft^2/ft^3, and
m_x...moisture of extinction, %

are the parameters that are quantified in the NFDRS fuel models. A fuel model is a set of the fuel particle and fuel bed descriptors required as inputs to the Rothermel spread model, plus wind reduction and rate-of-spread normalizing factors that are discussed later.

In the 1972 NFDRS, nine fuel models were provided. The users and the NFDRS technical committee wanted the number of fuel models increased in the 1978 NFDRS to supposedly improve resolution and representativeness. The researchers assigned to the project did not agree and recommended that the number of models be reduced or, at the very least, be held to nine. Their position was based on the following:

1. Fire-danger ratings are required for areas on the order of 10^4 to 10^5 acres; low on any scale of resolution.
2. It was not logical to incorporate high resolution fuel descriptors when fuel moistures and wind are resolvable at such low levels (one observation per day per 10^5 acres).
3. The information required to construct fuel models was (and still is) very limited.
4. The fire behavior prediction system developed by Rothermel and Albini (FBO package reference) and Rothermel (1983) was designed to satisfy the "1- to 100-acre/10 minutes to 1-hour resolution" fire behavior prediction needs of the fire manager.

The technical committee prevailed and the result was an array of 20 fuel models.

Eight of the nine 1972 NFDRS fuel models were retained—model F was redefined to represent intermediate age (7 to 15 years old) mixed chaparral. (The original model F represented very young stands of brush that were essentially fireproof.) Data for the original nine fuel models were taken principally from Byram (1959); Philpot (1968, 1970); Countryman and Philpot (1970); and Brown (1970a,b,c). Twelve totally new models were developed.

The selection of the twenty fuel situations to be modeled was done by the researchers subjectively. The first step was a survey of fuel types entered on fire reports by nine Forest Service Regions, the BLM, and

several State fire management agencies. A consolidated list was produced after eliminating overlaps and duplications. From that list, 20 fuel types were selected for modeling based on:

1. Significance as a fire type,
2. Interest expressed by fire managers, and
3. The availability of fuels and fire behavior data with which to develop and test the models.

Some of the fuel situations matched the assumptions of uniformity, continuity, and uniform distribution of size classes very well, and enough data existed for straightforward modeling. These fuels include the grass models (A, L, and N), slash models (I, J, and K), and the needle litter of southern plantations, western pines, and short needled conifers (P, U, G, and H). There was heavy reliance on Hough and Albini's work (1978) with the palmetto-gallberry association to put the southern rough (D) and pocosin (O) models together (D emulates a 7-year rough). The B and F models (California mixed chaparral and intermediate brush) approximate the models developed by Rothermel and Philpot (1973) and adapted by Van Gelder (1976) for FIRECAST.

The pine grass savanna (C) and sagebrush-grass (T) are combinations of grass and litter, and grass and shrubs; they violate the assumptions of uniformity and reflect art more than science.

The models constructed for Alaska—black spruce and tundra (Q and S)—are terribly artificial, but the outputs are reasonable, judging from the limited amount of fire behavior data available from Alaskan and Canadian sources.

The fuel modeling procedure incorporated a great deal of repetitive building and evaluating. As much information as possible about a particular fuel situation was gathered, but "best guesses" were used for a fuel model when nothing concrete was available. The prototype fuel model was then tested using archived fire-weather data to generate daily values of rate-of-spread and flame length. The predictions were compared to fire behavior observations, or if none were available, the results were subjectively evaluated by the researchers.

Once a preliminary set of fuel models had been developed, the fire-danger estimates produced using these models were evaluated by fire managers. The evaluation included:

1. The rate-of-spread (SC) and flame length (0.1 X BI) predictions, and
2. The seasonal profile of the NFDRS indexes, components, and live fuel moistures.

The fire-weather data sets for the field tests were specified by the evaluators. They selected a wet year, a dry year, and any other period of time that offered characteristics a fire-danger rating system should pick up.

Parameters were adjusted and the performance reevaluated several times in some cases before model parameters were settled on. Table 5 lists the 20 fuel models in the 1978 NFDRS. Fuel model parameters are summarized in appendix B. Narrative descriptions and a key for selecting an appropriate fuel model are included in the 1978 NFDRS summary publication (Deeming and others 1977).

Table 5.—List of fuel models in the 1978 NFDRS (Models A-E, G-I were included in 1972 NFDRS; model F represents a different fuel than in 1972 NFDRS)

Fuel model	General description
A	Western annual grasses
B	California mixed chaparral
C	Pine grass savanna
D	Southern rough
E	Hardwoods (winter)
F	Intermediate brush
G	Short needle pine (heavy dead)
H	Short needle pine (normal dead)
I	Heavy logging slash
J	Intermediate logging slash
K	Light logging slash
L	Western perennial grass
N	Sawgrass
O	High pocosin
P	Southern pine plantation
Q	Alaskan black spruce
R	Hardwoods (summer)
S	Tundra
T	Sagebrush-grass
U	Western long-needled conifer

DEAD FUEL MOISTURE MODELS

The dead fuel moisture models in the 1978 NFDRS are based on the theory described in section titled "Classification of Fuel Components," except when fuel moisture sticks were weighed as part of the fire-weather observation. In those cases, the 1-hour and 10-hour fuel moistures are computed using the analog stick moisture content. The 100-hour and 1,000-hour fuel moistures are computed from Fosberg's theoretical solutions, using an average equilibrium moisture content (called boundary conditions) for 24 and 168 hours, respectively. The solutions are based on two equations, one from Fosberg (1970):

$$\delta\mu/\Delta\mu = (mc - mc_o)/(\overline{EMC} - mc_o) \tag{23}$$

and equation 5 from section titled "Classification of Fuel Components":

$$\delta\mu/\Delta\mu = 1 - \zeta(\exp(-T/\tau)) \tag{5}$$

where

$\delta\mu$ is the actual moisture content change (%) in the stress period, T,

$\Delta\mu$ is the potential moisture content change (%) for the stress period T, (mc_o − mc),

mc_o is the moisture content (%) at the beginning of the stress period T,

mc is the moisture content (%) at the end of the stress period (T+1),

$\overline{EMC}$ is the mean equilibrium moisture content (%)for the stress period (T),

ζ is the dimensionless similarity coefficient,

τ is the fuel particle timelag (h), and

T is the simulation (stress) period timestep (h).

Repeating again, ζ is empirically derived and valid only for particular combinations of T and τ at a specific time of the day.

The 1-Hour Timelag Fuel Moisture Model

The 1978 NFDRS gives two methods to calculate the 1-hour fuel moisture, but that developed for the California wildland fire-danger rating system (USDA 1958, revised 1968) is preferable:

$$mc_1 = (4EMC + mc_{10_k})/5 \quad (\%) \tag{24}$$

where

mc_{10_k} is the age-corrected fuel stick moisture (%, see next section titled "The 10-Hour Timelag Fuel Moisture Model"), and

EMC is the equilibrium moisture content (%) calculated using the temperature and relative humidity at the fuel-atmosphere interface.

Observation time relative humidity and temperature at the fuel-atmosphere boundary layer are estimated from lapse rates determined by Haltiner (1975) that are dependent on sky cover.

To adjust standard exposed instrument readings (4.5 feet from ground in shelter) of relative humidity and temperature to fuel level, the factors in table 6 are used.

Table 6.—Fuel-atmosphere interface temperature and relative humidity adjustment factors (from Haltiner 1975)

	Fraction sky cover:sky condition			
	0.0-0.1: Clear	0.1-0.5: Scattered	0.6-0.9: Broken	0.9-1.0: Overcast
Dry bulb temperature, °F (add)	25	19	12	5
Relative humidity (multiply)	0.75	0.83	0.91	1.0

If the fuel stick moisture (mc_{10_k} is not reported, the method described by Fosberg and Deeming (1971) is used. Combining equations 5 and 23 and solving for mc_1, Fosberg's basic diffusion equation becomes

$$mc_1 = mc_o + (EMC - mc_o)(1 - \zeta(\exp(-T/\tau)) \tag{25}$$

where

mc_1 is the 1-hour timelag fuel moisture (%) at time T and

mc_o is the 1-hour timelag fuel moisture at time (T−1).

The equation was solved sequentially for forty-eight 30-minute time periods, ending at a time in the midafternoon.

Using diurnal data from the O'Neill, Nebr., experiment (Lettau and Davidson 1957), a T value of 0.5 hours, and τ and ζ values of 1.0 yielded a simplified expression for 1-hour fuel moisture for midafternoon observation time:

$$mc_1 = 1.03 \text{ EMC } (\%) \tag{26}$$

where EMC is the calculated equilibrium moisture content at the fuel-atmosphere interface.

The 10-Hour Timelag Fuel Moisture Model

The preferred method for obtaining 10-hour fuel moisture is from fuel moisture sticks, corrected for stick aging. When analog stick weight (W_f) is measured:

$$mc_{10} = A_1C + BC(W_f - 100) \ (\%) \tag{27}$$

with

$$A_1 = a/60 \tag{28}$$
$$B = 1 + 0.02(a/30) \tag{29}$$
$$C = C_c/4 \tag{30}$$

where

W_f is the fuel stick weight (g),
a is the number of days since the sticks were set out,
C_c is the 1978 NFDRS climate class (1 to 4), and
100.0 is the ovendry weight of the fuel sticks (g).

The age correction as developed by Haines and Frost (1978) was changed to be functional on climate class because the original function over-estimated weight loss in dry climates. NFDRS climate classes are discussed in the section titled "Live Fuel Moisture Model."

When fuel sticks are not measured, the 10-hour fuel moisture is estimated in a manner similar to that for the 1-hour fuel moisture (also reported by Fosberg and Deeming 1971).

The diurnal O'Neill, Nebr., data were used and the basic diffusion equation (eq. 25) was solved in 4-hour time steps using $\zeta = 0.87$, T = 4 hours, and $\tau = 10$ hours to produce this estimate for a midafternoon observation:

$$mc_{10} = 1.28 \text{ EMC} \quad (\%) \tag{31}$$

where

EMC is the same EMC used to calculate the 1-hour fuel moisture.

This model works well for early afternoons in strong continental areas at the approximate latitude of Nebraska in the late summer. It tends to underpredict stick readings under other conditions.

FORECASTING THE 10-HOUR FUEL MOISTURE IN AFFIRMS

Accurately forecasting the next day's 10-hour timelag fuel moisture (TLFM) requires a more complex model that utilizes 24-hour maximum and minimum temperatures and relative humidities. The 24 hours between observation times is divided into two periods: the first from the basic observation time of day 1 (1400 hours) to 0600 hours of day 2 (assumed to be the time of minimum temperature and maximum relative humidity for the 24-hour period); and the second from 0600 of day 2 to the basic observation time of day 2.

The average temperatures and relative humidities for the two periods are estimated from predictions or observations for the three occasions (times). The predicted duration of precipitation during the two periods is included in the calculation of average boundary conditions for each period:

$$D_1 = [(16 - p_{d1})EMC_1 + (2.7p_{d1} + 76)p_{d1}]/16 \tag{32}$$
$$D_2 = [(8 - p_{d2})EMC_2 + (2.7p_{d2} + 76)p_{d2}]/8 \tag{33}$$

where

D_1 is the average boundary condition for the 16-hour period from 1400 on day 1 to 0600 on day 2,

p_{d1} and p_{d2} are the precipitation durations for the two periods (h),

EMC_1 and EMC_2 are the equilibrium moisture contents for the two periods derived from average temperature andrelative humidity for each period, corrected to the fuel-atmosphere interface.

The precipitation duration effect function ($2.7p_d + 76$) is from Fosberg (1972).

The next step is to predict the 10-hour fuel moisture at the end of the first period (0600 hours) using the observed (or computed) 10-hour fuel moisture at 1400 on day 1 and D_1 as initial values. The predicted value at 0600 (day 2) then becomes the initial value for predicting the 10-hour timelag fuel moisture at 1400 on day 2:

$$mc_{10_1} = mc_{10_0} - (D_1 - mc_{10_0})(1 - 1.1\exp(-16/10)) \tag{34}$$

and

$$mc_{10} = mc_{10_1} - (D_2 - mc_{10_1})(1 - 0.87\exp(-8/10)) \tag{35}$$

where

mc_{10_0} is the 10-hour TLFM at 1400 of day 1,
mc_{10_1} is the 10-hour TLFM at 0600 of day 2,
mc_{10} is the forecasted 10-hour TLFM at 1400 of day 2,
0.87 in eq. 35 is the ζ derived for eq. 31, and
1.1 in eq. 34 is the ζ derived for early mornings (0600).

AFFIRMS also allows direct predictions of 10-hour fuel moistures if methods such as that by Cramer (1961) have been developed for local use. Thus, if the predicted 10-hour moisture content is entered, the computational model is skipped.

The 100-Hour Timelag Fuel Moisture Model

The 100-hour model in the 1978 NFDRS first computes a 24-hour average boundary condition as an input to the basic diffusion equation. The boundary condition is determined from precipitation duration, maximum and minimum temperature, and relative humidity, and is for the 24-hour period from observation time on day 1 to observation time on day 2. When some of the above observation elements are missing (principally in FIRDAT), cruder methods are used for 100-hour timelag fuel moisture computations (Cohen and Deeming, in preparation).

The similarity coefficient (ζ) in the 1978 model was selected to produce the same solution as would the 1972 model, when the precipitation duration is 24 hours. The boundary condition is

$$D = [(24 - p_d)\overline{EMC} + (0.5p_d + 41)p_d]/24 \tag{36}$$

and the basic diffusion equation becomes

$$mc_{100} = mc_{100_0} + (D - mc_{100_0})(1 - 0.87\exp(-24/100)) \tag{37}$$

where

D is the 24-hour average boundary condition (%),

$\overline{EMC}$ is a weighted 24-hour average equilibrium moisture content (%), calculated from the day's maximum and minimum temperatures and relative humidities (see below),

p_d is the precipitation duration for the 24-hour period, and

mc_{100_0} and mc_{100} are the observed and predicted 100-hour timelag fuel moistures for observation times at days 1 and 2, respectively.

The 1978 computerized 100-hour timelag fuel moisture model calculates the 24-hour average equilibrium moisture content ($\overline{EMC}$, %) more effectively than in the 1972 NFDRS. The manual 1978 NFDRS (and the entire 1972 system) calculate $\overline{EMC}$ using arithmetic averages of a day's maximum and minimum temperature, and maximum and minimum relative humidity.

The 1978 computerized NFDRS derives $\overline{EMC}$ for both the 100-hour and 1,000-hour timelag fuels from a weighted average of two EMC's: one calculated from the day's maximum temperature and minimum relative humidity (EMC_{min}), and a second calculated from the day's maximum relative humidity and minimum temperature (EMC_{max}).

Weighting is based on day length, which improves seasonal response of NFDRS fuel moisture models. As day length shortens, nighttime conditions (EMC_{max}) are given more weight, thus promoting moisture recovery in the 100-hour and 1,000-hour timelag fuels. Conversely, as day length increases, daytime conditions (EMC_{min}) are given more weight, thus promoting additional moisture loss in the heavier fuels.

Under this scheme the weighted EMC is calculated by:

$$\overline{EMC} = [(n)EMC_{min} + (24 - n)EMC_{max}]/24 \tag{38}$$

where n is the hours of daylight (refer to appendix D for computational details and NFDRS index response).

Manual calculation of the 100-hour timelag fuel moisture in the 1978 NFDRS is simpler than in the 1972 method because no arithmetic is necessary (both systems assume a constant 24-hour mean temperature to simplify the calculations). Using average relative humidity and precipitation is a compromise, but it does retain most of the calculated moisture response.

There are three types of missing data that are considered in the 100-hour fuel moisture computations. If only precipitation duration is missing, it is estimated by:

$$p_d = (p_a + 0.02)/p_r \tag{39}$$

rounded to the nearest whole hour, where

p_d is the precipitation duration (limited to a maximum of 8 hours),

p_a is the 24-hour precipitation amount (inches), and

p_r is 0.25 inch/h for climate classes 1 and 2, and 0.05 inch/h for climate classes 3 and 4.

If extreme values for relative humidity are missing, but temperature extremes are available, maximum and minimum relative humidities are estimated by assuming the air mass does not change over the 24 hours and the specific humidity is constant. The day's observation time relative humidity is combined with the day's temperature extremes to estimate relative humidity extremes (Cohen and Deeming, in preparation).

If daily temperature extremes are missing, EMC_{min} is assumed to be the observation time EMC, and EMC_{max} is a climate class dependent default value. For climate

classes 1 and 2, EMC_{max} is 15 percent; for classes 3 and 4, it is 23 percent.

The weighted EMC is then computed from equation 38; the daily boundary condition from equation 36; and the 100-hour moisture content from equation 37.

The 1,000-Hour Timelag Fuel Moisture Model

The 1,000-hour timelag fuel moisture model retains the basic format of the 100-hour model, but requires an assessment of the average boundary conditions for 7 days or 168 hours instead of 24 hours (Fosberg and others 1981). A 7-day interval was chosen so that the calculation would be done the same day each week in the manual version.

The mean 7-day boundary value (D, %):

$$D = (D_1 + D_2 + ... + D_7)/7 \qquad (40)$$

is computed from the 24-hour average boundary values (day length weighted) for the previous 7 days:

$$D_n = [(24 - p_{dn})EMC_n + (2.7p_{dn} + 76)p_{dn}]/24 \qquad (41)$$

where n denotes the n^{th} day and EMC_n is weighted as described in the 100-hour model.

The diffusion equation then becomes

$$mc_{1000} = mc_{1000_0} + (mc_{1000_0} - D)(1 - 0.82 \exp(-168/1,000)) \qquad (42)$$

where

mc_{1000} is the predicted 1,000-hour fuel moisture,
mc_{1000_0} is the initial value from 7 days prior,
D is the 7-day average boundary condition (%), and
0.82 is the derived ζ value.

In manual calculations, the 7-day change in 1,000-hour timelag fuel moisture is calculated with a nomogram and manually added to (or subtracted from) the 1,000-hour timelag fuel moisture from 7 days previous. This arithmetic is not buried in the nomogram because the 7-day change is a variable needed for input into the NFDRS live fuel moisture model. As a result, the 1,000-hour timelag fuel moisture must be calculated for all fuel models in spite of the absence of 1,000-hour fuels in many. The computer version does this bookkeeping automatically.

RESPONSE TO DROUGHT

By itself the 1,000-hour timelag fuel moisture is a good indicator of the severity of a medium term (4- to 6-month) drought event. The 1,000-hour timelag fuel moistures calculated using data from different climate classes showed minimum values during recent drought years to be characteristic of the climate class. The following tabulation summarizes some cases studied:

Location	Year	Season minimum 1,000-hour timelag fuel moisture,%
Walport, Oreg.	1973	21
Fort Meyers,Fla.	1970	14
Ely, Minn.	1976	11
Bonners Ferry, Idaho	1973	9
Lytle Creek, Calif.	1972	5

As another example, the following tabulation portrays the frequency of seasonal minimum 1,000-hour timelag fuel moisture values at Ninemile, Mont., for the years 1965–75. In 1966 and 1967, both very severe fire years, the 1,000-hour TLFM dropped to 9 percent.

Season minimum 1,000-hour TLFM (%)	Frequency
9	2
10	0
11	0
12	3
13	4
14	1
15	1

LIVE FUEL MOISTURE MODELS

Improvements in the Rothermel (1972) fire model made it possible to treat live fuel more realistically in the NFDRS update. Live fuels can now act as either a heat sink or heat source. Live fuels become a heat source when their moisture content drops enough to allow dessication and ignition during dead fuel combustion. If their moisture content remains above a critical level (live fuel moisture of extinction), live fuels do not burn but act as a heat sink (Albini 1976a).

The live fuel moisture model provides more analytical and consistent estimates of live fuel moisture, replacing the herbaceous vegetation transects required by the 1972 NFDRS. The following section draws heavily upon Burgan (1979).

Although it is not based on rigorous principles of plant physiology, the live fuel model broadly approximates the moisture content of living herbaceous plants, and the leaves and twigs of small woody shrubs.

In the original live fuel model proposed by Rothermel, plant moisture was treated as a function of the Keetch-Byram (1968) drought index. Several empirical factors required to control plant response to drying and wetting, however, could not be derived for all climates.

Development of the 1978 NFDRS led to the discovery that the 1,000-hour timelag fuel moisture function responded to wetting and drying cycles similar to those expected for live fuel. Thus, the 1,000-hour timelag fuel moisture serves as the basic meteorological factor for calculating live woody fuel moisture and is used in a modified form to emulate the wetting and drying cycles of live herbaceous fuels.

Plants adapted to various moisture regimes respond differently to rainfall anomalies: those adapted to moist environments lose moisture faster during drought than those from dry environments. The 1978 live fuel moisture model, therefore, provides drying rates by climate class.

Although the United States can be divided into many climatic zones, four classes were judged adequate to provide the broadscale plant moisture responses needed for rating fire danger. These four climate classes are adapted from Thornthwaite's (1931) earliest climate

classification system. Arid and semiarid provinces are grouped into a single class; true desert is of little practical concern to fire management. And when considering fire behavior, the subhumid province belongs to the humid province rather than the dry, subhumid province. The climate class descriptions, general geographic areas to which they apply, and the vegetative characteristic of each are provided in table 7. Figure 6 maps the climate classes for the contiguous United States and Alaska.

Climate class defines different linear drying rates for annuals, perennials, and woody plants, but within a particular climate class, a single drying rate is assumed for live woody plants throughout a growing season. In live herbaceous plants, drying occurs in two stages: green stage when herbaceous moisture is above 120 percent, and transition stage when moisture is between 120 and 30 percent. In the green stage both annuals and perennials dry at the same rate, but in the transition stage annuals exhibit faster drying rates than perennials.

The endpoints of the drying curves are required to define drying rates. First, weather data from several locations within each climate class were used to plot seasonal 1,000-hour timelag fuel moisture profiles. Typical plant moistures for each climate class and vegetation type (woody, annual, and perennial) were then matched with these profiles. Because measurements of seasonal moisture variation in woody and herbaceous plants were not generally available from different regions of the United States, the live fuel model was calibrated to produce reasonable moisture values. Table 8 shows the specific performance objectives.

Maximum live fuel moistures were chosen to be 250 percent for herbaceous fuels and 200 percent for live woody shrubs, at 25 percent 1,000-hour timelag fuel moisture. Towards the lower end of the moisture scale herbaceous plants were considered cured at 30 percent moisture content and woody plants dormant if their moisture content dropped to 50 percent. The minimum

Table 7.—The 1978 NFDRS climate classes (from Deeming and others 1977)

NFDRS climate class	Thornthwaite (1931) humidity province	Characteristic vegetation	Regions
1	Arid	Desert (sparse grass and scattered shrubs)	Sonoran deserts of western Texas, New Mexico, southwest Arizona, southern Nevada, and western Utah; and the Mojave Desert of California.
	Semiarid	Steppe (short grass and shrubs)	The short grass prairies of the Great Plains; the sagebrush steppes and pinyon-juniper woodlands of Wyoming, Montana, Idaho, Colorado, Utah, Arizona, Washington, and Oregon; and the grass steppes of the central valley of California.
2	Subhumid (rainfall deficient in summer)	Savanna (grasslands, dense bush, and open conifer forests)	The Alaskan interior; the chaparral of Colorado, Arizona, New Mexico, the Sierra Nevada foothills, and southern California; oak woodland of California; ponderosa pine woodlands of the West; and mountain valleys (or parks) of the Northern and Central Rockies.
3	Subhumid (rainfall adequate in all seasons)	Savanna (grasslands and open hardwood forests)	Blue stem prairies and blue stem-oak-hickory savanna of Iowa, Missouri, and Illinois.
	Humid	Forests	Almost the entire eastern United States; and those higher elevations in the West that support forests.
4	Wet	Rain forest (redwoods, and spruce-cedar-hemlock)	Coast of Northern California, Oregon, Washington, and southeast Alaska.

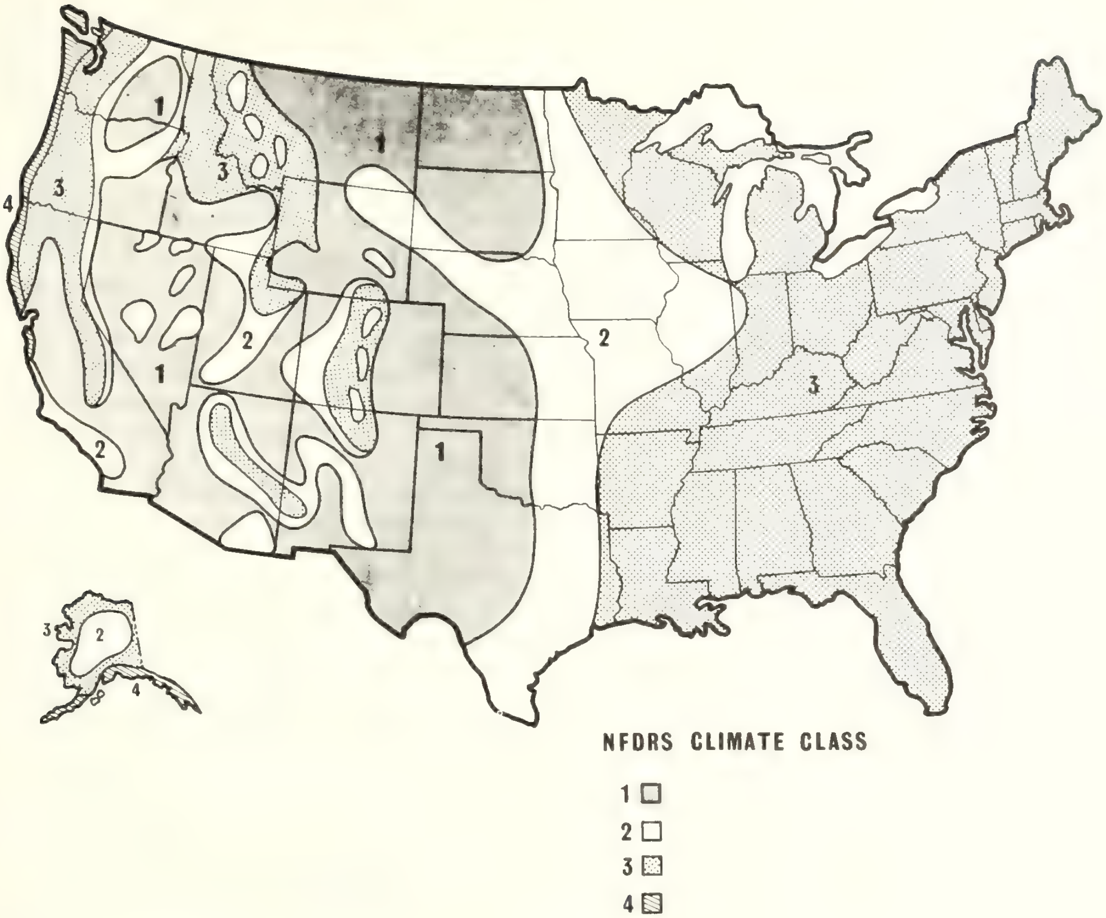

Figure 6.—1978 NFDRS climate class (from Deeming and others 1977, p. 5).

Table 8.—Minimum allowable moisture content of live fuels in live fuel models (from Burgan 1979)

Type of season	Grasses and forbs: Annuals	Grasses and forbs: Perennials	Shrubs, twigs, and foliage
	Percent		
Wet	30 (Late cure)	>80	>110
Normal	<30	50-80	80-100
Dry	<30 (Early cure)	<50	50-80

woody and herbaceous moistures were matched with typical minimum 1,000-hour timelag fuel moistures and minimum X1,000-hour values, respectively, for each climate class. Table 9 provides the slopes and intercepts of the drying curves for each climate class.

A dynamic live fuel moisture algorithm simulates greening and curing of herbaceous fuels by transferring fuel load between the live herbaceous class and the 1-hour timelag class as the herbaceous fuel moisture varies between 30 and 120 percent during the growing season.

Rothermel provided the empirical data used for development and initial testing of the live fuel moisture model. He used the xylene distillation technique for determining moisture content to construct profiles of herbaceous and woody plants near Missoula, Mont., during the 1975 and 1976 fire seasons. Developed to emulate these particular moisture profiles, the model was then adjusted to produce reasonable profiles for the rest of the United States.

Herbaceous Fuel Moisture

Although relating herbaceous fuel moisture directly to the 1,000-hour timelag fuel moisture proved reasonable for periods of drying, excessive fuel moisture recovery was predicted during periods of precipitation. A function was developed to decrease at the same rate as the 1,000-hour timelag fuel moisture, but to increase more slowly.

During the growing season this value is

$$X_{1000} = X_{y1000} + k_1 k_2 (\Delta mc_{1000}) \qquad (43)$$

where

X_{1000} is the day's live fuel moisture recovery value, (%),
X_{y1000} is yesterday's X_{1000} value, (%),
k_1 is a drying/wetting factor (dimensionless),
$k_1 = 1$ if $\Delta mc_{1000} < 0$ (drying regime)
$k_1 = 0.0333(mc_{1000}) + 0.1675$ otherwise
k_2 is a temperature factor (dimensionless),
$k_2 = 1.0$,
if the day's average temperature $>$ 50 F (10° C)
$k_2 = 0.6$,
if the day's average temperature $\leq$ 50 F (10° C)
Δmc_{1000} is the 24-hour change in mc_{1000} (%).

k_1 limits the increase in herbaceous fuel moisture due to precipitation. It is scaled to allow the X_{1000} value to duplicate the 1,000-hour timelag fuel moisture when the 1,000-hour timelag fuel moisture is 25 percent or more.

k_2 reduces the response of the X_{1000} value to compensate for plants' slower physiological processes during cool weather. Figure 7 compares the 1,000-hour timelag moistures with the X_{1000} value.

Prior to spring green-up, herbaceous fuel is assumed to be completely cured, letting herbaceous fuel moisture (mc_h) equal the 1-hour TLFM.

During spring green-up, live herbaceous fuel moisture increases gradually from the 1-hour timelag fuel moisture. The live fuel model accommodates gradual green-up at the request of eastern United States users who feared that the instantaneous green-up originally proposed would not properly reflect the transition from high fire danger in early spring to low fire danger in summer. The green-up period length varies linearly from 7 days for climate class 1 to 28 days for climate class 4. The length of green-up was scaled to climate class because plants growing in drier climates typically respond more quickly to favorable growing conditions than plants in wetter climates.

When a spring flush of growth becomes generally apparent, the user specifies the beginning of green-up. Herbaceous fuel moisture is then calculated according to the equation:

$$mc_h = mc_1 + gu[(a_h + b_h X_{1000}) - mc_1] \qquad (44)$$

where

a_h and b_h are climate-dependent intercept and slope for annuals or perennials from table 9,
X_{1000} is the fuel moisture recovery value from eq. 43,
mc_1 is the 1-hour timelag fuel moisture, and
gu is the elapsed fraction of the green-up period.

If a second green-up occurs during the growing season, the X_{1000} value is again set equal to the 1,000-hour timelag fuel moisture. The same green-up procedure is followed, except herbaceous moisture increases from its current value instead of the 1-hour timelag fuel moisture.

After the green-up period is complete ($gu = 1.0$), the herbaceous fuel moisture is

$$mc_h = a_h + b_h X_{1000} \; (y = a + bx). \qquad (45)$$

Table 9.—Regression slopes and intercepts for drying rates of live fuels (from Burgan 1979)

	Climate class							
	1		2		3		4	
Fuel	Slope	Intercept	Slope	Intercept	Slope	Intercept	Slope	Intercept
Woody fuels	7.5	12.5	8.2	-5.0	8.9	-22.5	9.8	-45.0
Herbaceous fuels								
Annuals and perennials - green stage	12.8	-70.0	14.0	-100.0	15.5	-137.5	17.4	-185.0
Annuals - transition stage	18.4	-150.5	19.6	-187.7	22.0	-245.2	24.3	-305.2
Perennials - transition stage	7.4	11.2	8.3	-10.3	9.8	-42.7	12.2	-93.5

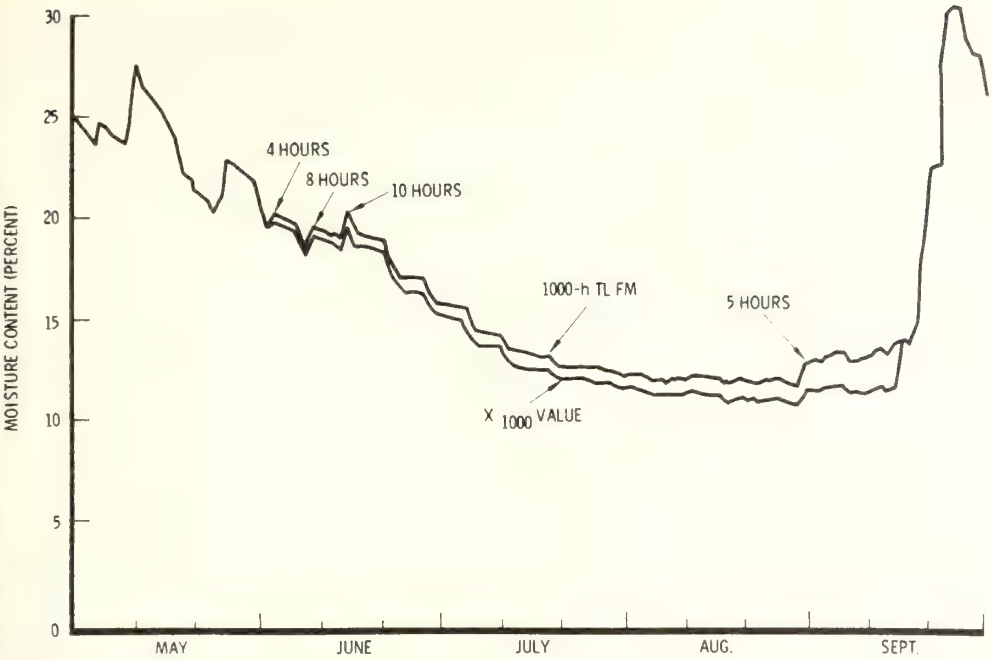

Figure 7.—Comparison of X_{1000} to 1,000-hour values in live fuel moisture model (from Burgan 1979, p. 8).

When the user specifies that the herbaceous vegetation has cured phenologically, or frozen, herbaceous fuel moisture again equals the 1-hour timelag fuel moisture. A freeze occurs at or below a minimum temperature of 25° F, or when minimum temperatures between 32° and 26° F occur five times.

Figure 8 illustrates the relationship between the X_{1000} value and the annual and perennial herbaceous moistures.

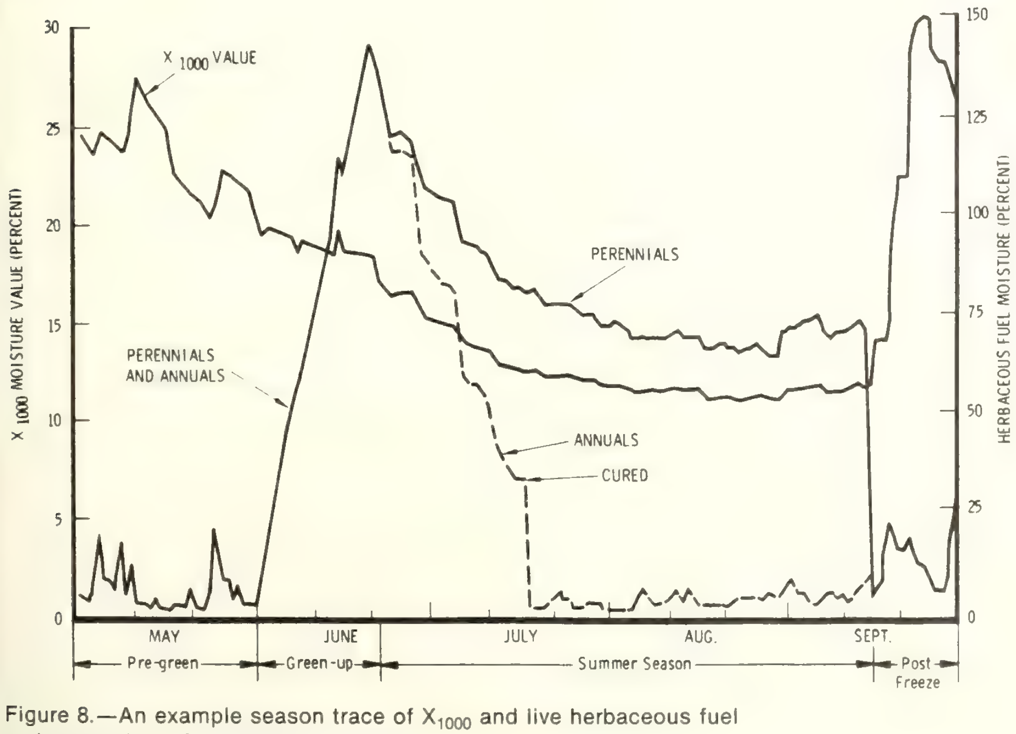

Figure 8.—An example season trace of X_{1000} and live herbaceous fuel moisture values (from Burgan 1979, p. 9).

TRANSFER OF FUEL BETWEEN LIVE AND DEAD CATEGORIES

Before green-up the entire herbaceous fuel load falls under the 1-hour class. During green-up the live herbaceous fuel load transfers from the 1-hour to the live fuel category as herbaceous moisture increases from 30 to 120 percent. At levels greater than 120 percent the herbaceous fuel load reaches its maximum, and the 1-hour timelag fuel load its minimum.

As herbaceous plant moisture decreases later in the growing season and varies between 30 and 120 percent, the load of perennial herbaceous fuels is shifted between the live and dead fuel categories. This indicates a transition stage. One hundred and twenty percent approximates the upper limit for transition, roughly defining the moisture content at which new growth is complete and foliage mature. Thirty percent was chosen as the lower limit because it approximates the fiber saturation point, below which herbaceous plants are assumed dead.

The process differs slightly for annual herbaceous plants. Following green-up the model does not allow the moisture content of annuals to increase. The fuel load for annuals transfers from the live category to the dead category, never in the reverse direction, as allowed with perennials. At 30 percent moisture content (after phenological curing or following a freeze in the fall), all the herbaceous fuels have been added back to the 1-hour timelag class.

The fuel load transfer equations are:

$$W_{1hd} = W_{1h} + W_h f \qquad (46)$$

$$W_{hg} = W_h(1 - f) \qquad (47)$$

where

$f = -0.0111mc_h + 1.33$ and $0 \leq f \leq 1.0$

and

W_{1hd} is the total load of 1-hour timelag fuel, including dead herbaceous fuel transferred to the 1-hour timelag category,

W_{1h} is the load of the 1-hour timelag fuel before inclusion of any cured herbaceous material,

W_h is the total load of herbaceous fuel,

f is the fraction of the herbaceous fuel that is to be transferred to the 1-hour timelag class,

W_{hg} is the load of herbaceous fuel that is still green, and

mc_h is the herbaceous fuel moisture.

Figure 9 shows herbaceous fuel load changes in relation to moisture content changes.

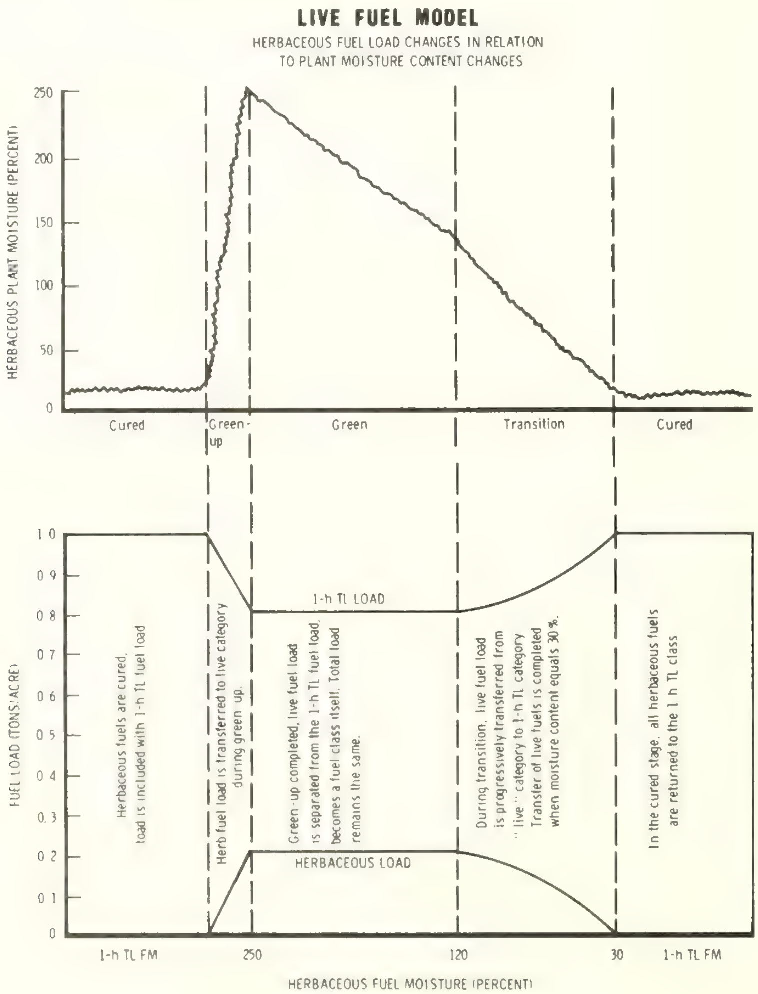

Figure 9.—Stylized live fuel moisture model load transfer function (from Burgan 1979, p. 11).

Figures 10 and 11 give examples of fuel transfer between live and dead categories for perennial and annual grasses. Herbaceous moisture will typically approach 250 percent at completion of green-up, but given a dry spring or late green-up, herbaceous moistures peak at lower values.

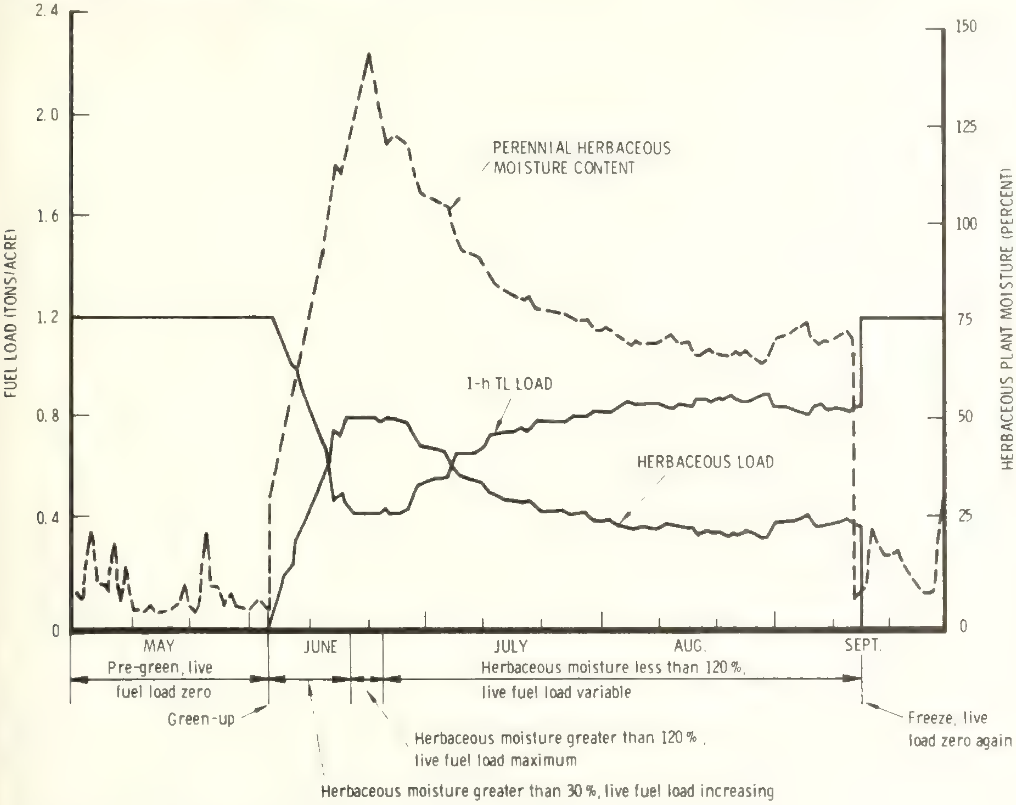

Figure 10.—Typical seasonal trace of live fuel moistures and resulting 1-hour load transfer between dead and live categories for perennial herbaceous fuels (from Burgan 1979, p. 12).

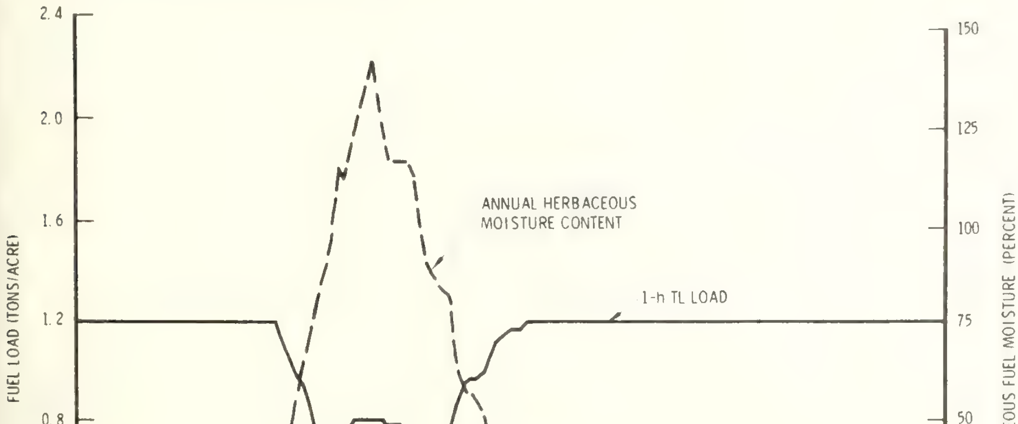

Figure 11.—Typical seasonal trace of live fuel moistures and resulting 1-hour load transfer between dead and live categories for annual herbaceous fuels (from Burgan 1979, p. 13).

Woody Fuel Moisture Model

Prior to spring green-up, woody shrubs are assumed dormant, and the woody fuel moisture (mc_w) held constant. Measurements of chamise leaf moisture in southern California indicate minimum values for woody plants in climate class 2 is about 60 percent (Dell and Philpot 1965). Similarly, measurements in the Southwest suggest a minimum woody moisture content of 70 percent for climate class 3 (Blackmarr and Flanner 1968). Pregreen mc_w values are defined as 50, 60, 70, or 80 for climate classes 1, 2, 3, or 4, respectively. During spring green-up, woody moisture gradually increases from the pregreen minimum:

$$mc_w = mc_{wo} + gu[(a_w + b_w mc_{1000}) - mc_{wo}] \qquad (48)$$

where

mc_{wo} is the pregreen minimum moisture,

a_w and b_w are climate-dependent intercept and slope from table 9,

mc_{1000} is the 1,000-hour timelag fuel moisture, and

gu is the fraction of the green-up period that has elapsed.

If a second green-up occurs during a growing season, woody fuel moisture increases from its current value instead of from the pregreen value.

After green-up completion (gu = 1) woody fuel moisture is

$$mc_w = a_w + b_w mc_{1000}. \qquad (49)$$

When the shrubs become dormant, woody fuel moisture is set back to the minimum value specified by the climate class. Figure 12 illustrates a typical woody fuel moisture profile and its relationship to 1,000-hour timelag fuel moisture.

FIRE BEHAVIOR MODEL

The Rothermel (1972) mathematical fire model provided an excellent method for systematically integrating fuels, weather, and topographic information to determine potential fire behavior, hence fire danger, in a homogeneous fuel bed.

The fire behavior portion of the NFDRS consists of the spread component (SC) and the energy release component (ERC). Using relationships developed by Byram (1959) and Albini (1976b), these components are combined in the burning index (BI). The BI reflects the potential containment problem presented by a single fire. It is linearly related to the predicted flame length at the head of a fire.

The fire model predicts fire spread and intensity in homogeneous fuel, based solely on static fuel and environmental properties assessed prior to ignition, not dynamic fire variables such as temperature, heat fluxes, and induced winds.

By using weighting factors assigned to the various fuel sizes, the fire model can accept heterogeneous fuel arrays composed of various-sized fuel particles. By weighting various parameters, attributes of heterogeneous fuel arrays are characterized for the fuel bed. Thus, while a particular fuel bed may have four dead fuel components, each with its own surface area-to-volume ratio, it has a singular "characteristic" surface area-to-volume ratio and "characteristic" fuel moisture, dependent on the weighting factors. The assumption of horizontal and vertical fuel continuity (and thus a uniform packing ratio and bulk density) throughout the bed is maintained.

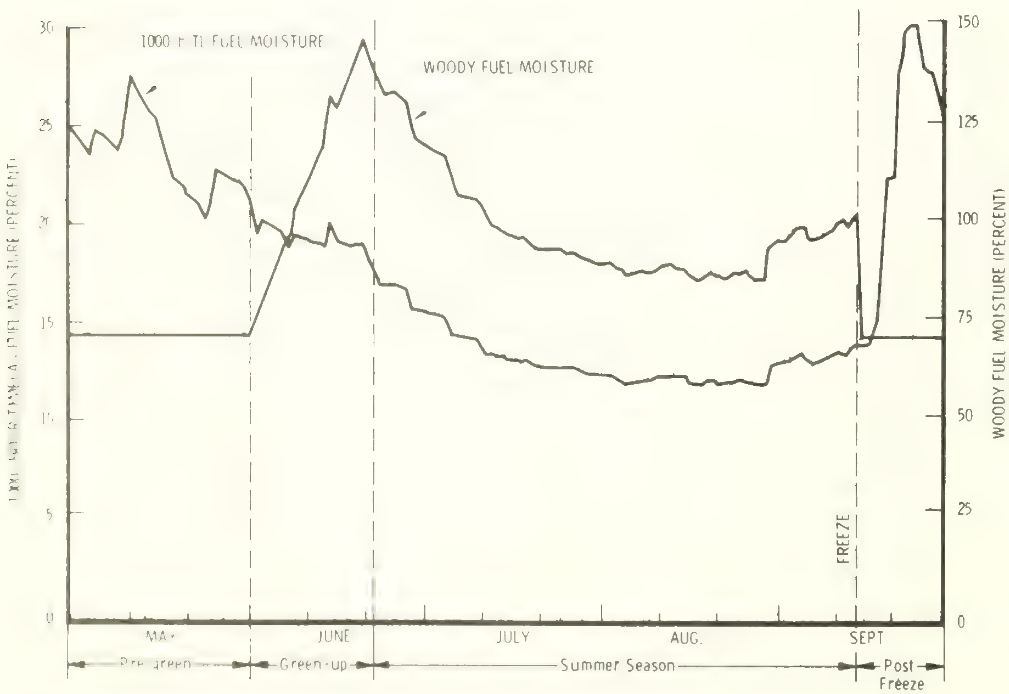

Figure 12.—A typical woody fuel moisture profile and its relationship to the 1,000-hour timelag fuel moisture (from Burgan 1979, p. 14).

Fire Model Parameter Weighting

Fuel arrays consist of particles of various sizes, some live and some dead. A method of weighting surface area-to-volume ratios (σ) and fuel moisture content (m_f) was developed to synthesize these varied parameters into a single, characteristic value for use in the fire model.

Rothermel (1972) introduced surface-area weighting for calculation of rate of spread. Weighting fuels by surface area eliminated making arbitrary decisions about which fuel sizes to include and which not to include as fire model inputs. A singular characteristic parameter is determined by weighting parameters in a fuel array composed of a mixture of particle sizes.

The concept of a unit fuel cell facilitates understanding of fuel size-class distribution. A unit fuel cell is the smallest volume of fuel within a stratum of mean depth that has sufficient fuel to statistically represent fuel in the entire complex. Now define:

$\bar{A}_T$ as the mean total surface area of fuel per unit fuel cell,

$\bar{A}_i$ as the mean total surface area of fuel of i^{th} category perunit fuel cell, and

$\bar{A}_{ij}$ is the mean total surface area of fuel of j^{th} size class and i^{th} category per unit fuel cell,where

i is the fuel category (dead = 1, living = 2), and

j is the fuel size class (1 = 1-hour, 2 = 10-hour, etc.).

The mean total surface area per unit fuel cell of each size class with each category is determined from the mean loading of that size class and its surface-area-to-volume ratio and particle density:

$$\bar{A}_{ij} = (\bar{\sigma}_{ij}\bar{W}_{ij})/\varrho_p. \tag{50}$$

The mean total surface area of the i^{th} category per unit fuel cell and the mean total surface area per unit fuel cell are then obtained by summing the areas within each category and within the fuel cell with equations 51 and 52:

$$\bar{A}_i = \sum_{j=1}^{3} \bar{A}_{ij} \tag{51}$$

$$\bar{A}_T = \sum_{i=1}^{2} \bar{A}_i. \tag{52}$$

Two weighting parameters are then calculated and used to weight fuel particle, fuel bed, and moisture content parameters throughout the fire spread model:

$$f_{ij} = \bar{A}_{ij}/\bar{A}_i \tag{53}$$

$$f_i = \bar{A}_i/\bar{A}_T \tag{54}$$

FIRE BEHAVIOR COMPONENTS

Spread Component (SC)

In the 1978 NFDRS, SC is numerically equivalent to the predicted rate of spread, rounded to the nearest whole number. The SC algorithm is the unmodified Rothermel fire spread model, with the fuel elements weighted by surface area:

$$SC = kR \tag{55}$$

where

k is a SC scaling factor (1.0 min/ft), and

R is the predicted rate of spread (ft/min).

WIND AND SLOPE IN THE 1978 NFDRS

Windspeed and slope enter into the Rothermel rate-of-spread equation through coefficients functional upon wind, slope, and fuel bed properties. Windspeed measured at the 20-foot level (10-minute average) is reduced to midflame height (as required for rate-of-spread computations) through a wind reduction factor.

Wind Reduction Factors

Ratios of the windspeed at roughly the midflame height to the 20-foot standard height were calculated for grass, shrub, and timbered areas assuming a standard logarithmic wind profile. Using variable roughness lengths, the ratios fell within the range of 0.4 to 0.6.

As such, wind reduction factors were made a fuel model parameter. For the grass-type fuel models, 0.6 is used. For the shrub and brush fuel models 0.5 is used; and for the timber fuel models the midflame windspeed is 0.4 of the 20-foot windspeed. The wind factor (ϕ_w) is then calculated as described by Rothermel (1972, eqs. 47−50).

Slope Classes

The slope classes in the 1978 NFDRS were selected so the slope coefficient (ϕ_s) would double from one class to the next higher class (slope class 5 has 16 times the effect [2^4] on rate of spread as slope class 1). Using a 90 percent slope for the slope class 5 midpoint, the slope factor (ϕ_s) for class 5 was computed from Rothermel's (1972) equation 5l. The class 4 ϕ_s was then computed by halving; class 3 by quartering; class 2 by taking one-eighth; and class 1 by taking one-sixteenth of the class 5 ϕ_s value.

The 1978 NFDRS slope classification scheme is summarized in table 10.

Table 10.—1978 NFDRS slope classes

NFDRS Slope class	Slope range	Effective class midpoint	Slope coefficient
	Percent	Percent	
1	0-25	22.5	0.267
2	26-40	31.8	.533
3	41-55	44.5	1.068
4	56-75	63.6	2.134
5	>75	90.0	4.273

Energy Release Component (ERC)

When the 1972 NFDRS was being developed, it was recognized that more than rate of spread of a potential fire had to be considered. Unfortunately, there are no models as definitive as the Rothermel model to quantify the effects of the condition of large fuels and the lowest layers of duff and litter on the fire behavior and fire management problem. There is no way that a fire-danger rating system would be acceptable if the ratings were solely based on the condition of fine fuels, which is the effect of surface-area weighting of fuel model parameters.

The authors decided that the spread component calculations should be totally consistent with rate-of-spread calculations in the Rothermel model; rate of spread is dominated by the condition of fine fuels. The approach selected to bring larger fuels into play was straightforward: use the fuel energy computations of the spread model—the reaction intensity—but base the influences of the different classes of fuel on their contribution to the total fuel load. Specifically, for the energy release component, the characteristic surface area-to-volume ratio and weighted fuel moisture of the fuel bed would be calculated using fuel class weighting factors based on loading, not surface area as in the spread component. This solution had no experimental basis.

For the 1978 revision it was hoped that work being done by Frank Albini with large fuel burnout would provide a concrete approach to the fuel energy problem. Unfortunately, Albini was not satisfied with the results of his effort and recommended that the 1972 loading-weighted approach be retained. Rothermel agreed with Albini, so with that counsel the 1972 procedure was retained.

Another decision made during the development of 1972 NFDRS was to change the form of the moisture-damping coefficient used in calculating the ERC. The curve form of this coefficient as developed by Rothermel is S-shaped. It declines rapidly with increasing fuel moisture at low fuel moistures and at moisture contents near the moisture of extinction; it is relatively flat in the midrange of fuel moistures. Again, a judgment was made: to develop and use a moisture-damping function that did not have the flattened "shoulder." The function,

$$\eta_e = 1 - 2(mc) + 1.5(mc)^2 - 0.5(mc)^3 \quad \text{(dimensionless)} \tag{56}$$

where

mc is the ratio of the load-weighted characteristic fuel bed moisture to the moisture of extinction (a damping coefficient is computed for both the dead and live fuel components),

was developed by Fosberg to assure a continuing increase in the ERC as fuel moistures in the midrange decreased. This function is used only for ERC computations, not spread component which uses

$$\eta = 1 - 2.59(mc) + 5.11(mc)^2 - 3.52(mc)^3 \tag{57}$$

which was developed by Rothermel. This function was retained in the 1978 NFDRS.

There was one significant change made to the ERC in the 1978 version that should be noted. The 1972 version computed ERC from a scaled loading-weighted reaction intensity (I_{Re}, Btu/ft^2-min):

$$ERC_{72} = j(I_{Re}).$$

In the 1978 version the residence time, τ_r, as defined by Anderson (1969) was included to make the ERC relatable to the total energy released per square foot during the flaming combustion stage (residence time):

$$ERC_{78} = k(I_{Re})(\tau_r) \tag{58}$$

where

k is a scaling factor (0.04 ft^2/Btu),

I_{Re} is the loading-weighted reaction intensity (Btu/ft^2-min), and

$$\tau_r = 384/\sigma \text{ (min)} \tag{59}$$

where σ is the surface area-weighted characteristic surface area-to-volume ratio of the fuel bed. This change was made for several reasons:

1. In the 1972 NFDRS τ_r was introduced at the point where the burning index (BI) was calculated. Since τ_r is fuel model dependent, a separate table to calculate the BI was required for each fuel model. Combining τ_r with I_{Re} made only one BI table necessary in the manual version.
2. Available heat per unit area, E:

$$E = \tau_r(I_{Re}) \text{ (Btu/ft}^2) \tag{60}$$

is more understandable and easier to relate to than reaction intensity.

3. Heat per unit area rather than another intensity-based index is more consistent with the original idea of a fuel energy phase as proposed by Keetch.

Burning Index (BI)

The 1978 burning index is the scaled predicted flame length, as calculated from the loading-weighted reaction intensity (I_{Re}), the surface area-weighted rate of spread (R), and the surface area-weighted residence time. A flame length relationship developed by Byram (1959):

$$F_L = 0.45(I)^{0.46} \tag{61}$$

where I is the fireline intensity (Btu/ft^2-min), was modified by Albini (1976a), and used to estimate flame length from which the BI is computed. The equation for flame length now incorporates the spread component and available energy (E):

$$F_L = j[(R/60)(I_{Re})(\tau_r)]^{0.46} \quad \text{(ft)} \tag{62}$$

$$F_L = j[(SC/60)(25(ERC))]^{0.46} \quad \text{(ft)} \tag{63}$$

where

R is the rate of spread (ft/min),

I_{Re} is the load-weighted reaction intensity (Btu/ft^2-min),

τ_r is the flaming residence time (min),

1/60 is a unit conversion (1 min/60 s), and

j is a coefficient (0.45 ft^2-sec/Btu).

Consequently,

$$BI = j_1 F_L \tag{64}$$

where j_1 is the BI scaling factor (10/ft).

IGNITION COMPONENT, RISK, AND OCCURRENCE INDEXES

The occurrence indexes, in conjunction with the burning index, compute the cumulative fire load index. The two fire occurrence indexes, man-caused (MCOI) and lightning-caused (LOI), give daily projections of the number of reportable man-caused and lightning-caused fires per million acres of protected land. Occurrence index values range from 0 to 100 and are scaled such that a value of 100 indicates an expected fire density of 10 fires/million acres.

The MCOI is a function of the ignition component (IC) and the man-caused risk: LOI is a function of a weighted IC and lightning-caused risk. Risk factors are the average expected number of firebrands on a given day by source (lightning- or man-caused). Determined from empirical models, risk factors allow users to compute scaling factors to adjust the risk models to specific regions (see Deeming and others 1977).

The IC is the probability that a reportable fire will result from a firebrand.

MCOI, tenfold the expected number of reportable man-caused fires per million acres on a given day, is

$$MCOI = IC(R_{MC}) \tag{65}$$

where R_{MC} is related to the total number expected man-caused firebrands for the day. Similarly, the LOI, or tenfold the number of reportable lightning fires per million acres for a given day is defined by:

$$LOI = IC(R_L) \tag{66}$$

where R_L is related to the number of expected lightning strokes.

Common to both MCOI and LOI, development of the IC will be reported first, followed by a discussion of the 1978 NFDRS risk models.

Ignition Component

The ignition component is calculated from the probability of ignition, P(I), the day's spread component, SC, and the maximum probable spread component SC_{max}. The SC_{max} is a fuel model parameter, calculated under a set of severe burning conditions (appendix B). This differs from the 1972 NFDRS ignition component, which was simply equal to the probability of ignition. The 1972 version of ignition probability used a moisture of extinction of 30 percent.

PROBABILITY OF IGNITION, P(I)

P(I) is the probability that a firebrand will start a fire (reportable or not) after landing on receptive fuels. This differs from the IC, which incorporates burning conditions (via the SC) to estimate the probability of a firebrand becoming a reportable fire. The P(I) predicts only whether the firebrand has sufficient energy to produce a successful ignition and is taken from an office report prepared by Mark Schroeder in 1969. Its development is included here because of its importance in the system's occurrence indexes and general unavailability. It is presented in original form of metric units.

The first step in determining P(I) is calculating the heat required to bring a fine fuel particle with a given mc_1 from its initial temperature to ignition temperature, the heat of preignition (Q_{ig}).

Heat of preignition (Q_{ig}, cal/g) is calculated by summing the following quantities:

A. The heat required to raise the temperature of the dry fuel from its initial temperature, T_o, to its ignition temperature, T_i (assumed to equal 320 °C),

B. The heat required to raise the moisture contained in the fuel from its initial temperature to the boiling point,

C. The heat of desorption,

D. The heat required to vaporize the moisture, and

E. The heat required to raise the temperature of water vapor contained in the fuel voids from the boiling point to ignition temperature.

The quantities are referred to as Q_a, Q_b, Q_c, Q_d, and Q_e, respectively.

To compute Q_a for a gram of fuel, the specific heat of dry fuel, c_f, is multiplied by the temperature range $T_i - T_o$. According to Stamm (1964), c_f varies with the temperature:

$$c_f = 0.266 + 0.00116T \tag{67}$$

where T is the average temperature between the ignition and initial temperatures. Thus

$$\begin{aligned} c_f &= 0.266 + 0.00116(320 + T_o)/2 \\ &= 0.4516 + 0.00058T_o \end{aligned} \tag{68}$$

and

$$Q_a = (T_i - T_o)(0.4516 + 0.00058T_o). \tag{69}$$

Calculating Q_b requires the temperature change from T_o to 100° C, multiplied by the mass of water and the specific heat (1.0 for water):

$$Q_b = m_f(100 - T_o) \text{ (cal/g)} \tag{70}$$

where m_f is the moisture content of the fuel (fraction).

Heat of desorption, Q_c, is the heat required to separate the bound water from the fibers, and equals the heat given off (heat of adsorption) when water vapor is adsorbed. From Stamm's (1964) figure 12−1, the following equation may be approximated:

$$Q_c = 280 \exp(-15.1m_f) \quad \text{(cal/g)}. \tag{71}$$

The total heat of desorption is obtained by integrating from m_f to $m_f=0$:

$$Q_c = 280 \int_0^{m_f} \exp(-15.1m_f)dm_f \tag{72}$$

$$Q_c = -18.54 \exp(-15.1m_f)\Big|_0^{m_f} \tag{73}$$

$$Q_c = 18.54(1 - \exp(-15.1m_f)) \quad \text{(cal/g)}. \tag{74}$$

The heat required to vaporize the moisture is the heat of vaporization times the mass of water:

$$Q_d = 640m_f. \tag{75}$$

Q_e, the heat required to raise water vapor in the voids from the boiling point to ignition temperature, was calculated to be negligible compared to Q_a, Q_b, Q_c, and

Q_d, and is omitted. Thus

$$Q_{ig} = Q_a + Q_b + Q_c + Q_d, \text{ or}$$

$$Q_{ig} = 144.51 - 0.266T_o - 0.00058T_o^2 - T_o m_f + 18.54(1 - \exp(-15.1m_f)) + 640m_f \text{ (cal/g)}. \tag{76}$$

Schroeder then proposed that if a firebrand lands on receptive fuels the probability of ignition as a function of Q_{ig} should be the product of the probability that a firebrand of a specific size will cause an ignition and the probability that the firebrand will be that size. The latter probability is dependent on the size distribution of firebrands, but this information was lacking. Schroeder used the findings of Blackmarr (1972) for the probability that a specific size firebrand will cause an ignition. This turned out to be reverse S-shaped curves (fig. 13) for slash pine litter at different moisture contents. To generalize this solution, Schroeder first defined a critical moisture content at $P(I) = 0$ for a specific firebrand, above which no ignition will take place. Using equation 76, he converted moisture content to Q_{ig} at a constant temperature. Defining Q_f as the heat from a firebrand at the critical moisture content and assuming that, at the critical moisture content, Q_f was equal to Q_{ig}, he transposed the curve to show P(I) as a function of $Q_f - Q_{ig}$.

Schroeder next reasoned that because firebrand size distributions were unknown one might deduce the distribution by knowing the shape of the $P(I/Q_{ig})$ curve. A clue as to the shape of this curve could be obtained from previous studies. John Keetch, in a circular letter dated April 19, 1960, reported on his survey of ignition studies used in fire-danger rating systems in various parts of the country. These were based on man-caused fire occurrence frequency and fine fuel moisture. He found considerable agreement among the studies. Figure 14 is a mean curve on log paper for these studies, with the highest value of ignition probability set at 1.5 percent moisture content. Some information on the size distribution of firebrands was desired to be contained in the index, but not the entire spectrum of firebrand sizes. Rather only those that caused ignition were included. Lacking any information as to where the truncation point might be, Schroeder arbitrarily set the lowest value of fuel moisture used at the 50 percent cumulative probability, replotted the curve from figure 14 on log-probability paper, and found that a straight line fit the data fairly well. At the same time he converted moisture content to Q_{ig} at constant temperature using equation 76.

The mathematical problem of backtracking from probability of ignition for a specific firebrand and the Q_{ig} curve to find the size distribution of firebrands turned

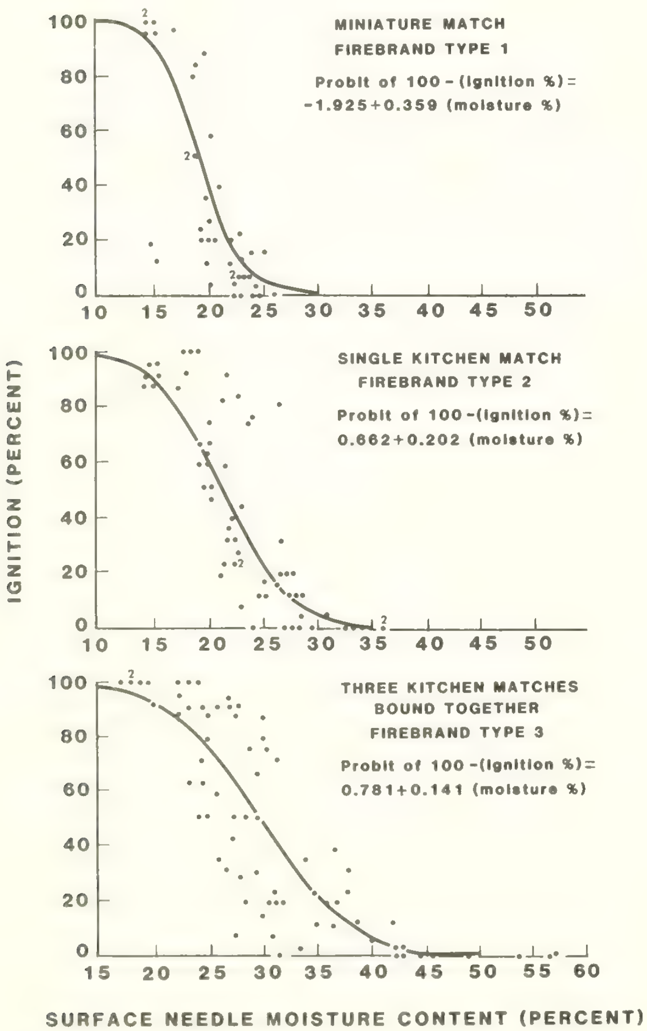

Figure 13.—Probability of ignition curves as a function of moisture content for three firebrand sizes (from Blackmarr 1972).

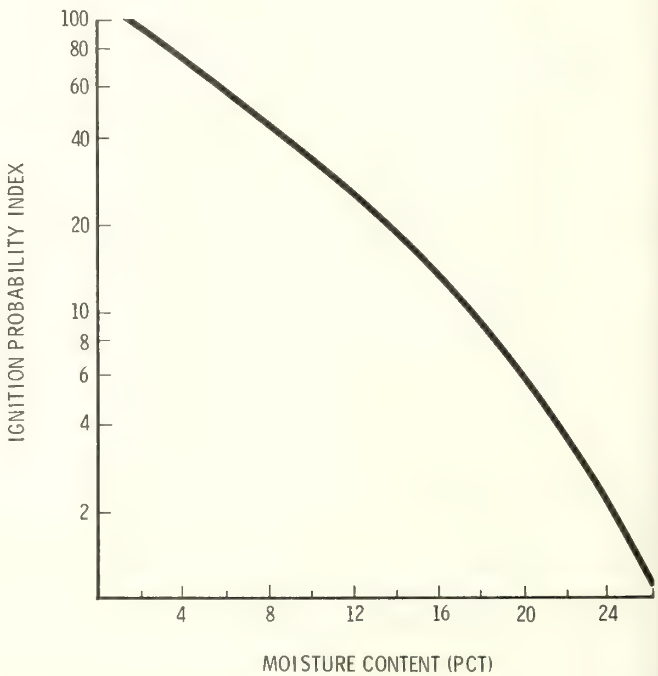

Figure 14.—Ignition probability as a function of dead fuel moisture content (from Schroeder 1969).

out to be intractable, and the effort was abandoned. Instead, the useful portion of the straight line function on the log-normal plot was solved numerically, yielding:

$$P(I/Q_{ig}) = 0.000048\chi^{4.3}/50 \quad (77)$$

where

$$\chi = (400 - Q_{ig})/10. \quad (78)$$

The general form of this equation is

$$P(I/Q_{ig}) = (k_3\chi^{k_4})/50.0 \quad (79)$$

where

$\chi = (Q_{igmx} - Q_{ig})/10,$

k_3 and k_4 are empirical constants,

Q_{igmx} is the heat or preignition for a fuel particle at the extinction moisture content, and

k_3, k_4, and Q_{igmx} are functions of the dead moisture of extinction.

Table 11 shows some computed values of k_3, k_4, and Q_{igmx} for various values of m_{xd}. The 1978 NFDRS uses the k_3 and k_4 values associated with $m_x = 25$ and $Q_{igmx} = 344$, although Schroeder developed the P(I) using $m_x = 30$ percent and $Q_{igmx} = 380$. The reason for this change was because the 30 percent used in the 1972 NFDRS was felt to be too high. An m_x of 20 percent was first proposed, but a value of 25 percent was finally used for the 1978 version.

The P(I) function is calibrated with other constants, P_1 and P_2, such that P(I) = 0 when $mc_1 = m_x = 25$, and P(I) = 100 when $mc_1 = 1.5$ percent. Table 11 shows other possible values of P_1 and P_2.

Ignition component is then computed from a function developed by Bill Main at the North Central Experiment Station. Using pooled data from Jackson (1977):

$$IC = P(I)(0.1)(SC_N)^{0.5} \quad (80)$$

where

$$SC_N = SC/SC_{max} \cdot 100 \text{ (maximum } SC_N = 100), \quad (81)$$

$$P(I) = (P(I)' - 0.00232)(100)/0.99767, \quad (82)$$

$$P(I)' = (0.000923\chi^{3.66})/50, \quad (83)$$

$$\chi = (344 - Q_{ig})/10, \quad (84)$$

and

SC is the day's spread component,

Q_{ig} is computed from equation 76,

$P_1 = 0.00232,$

$P_2 = 0.99767,$

$k_3 = 0.000923$, and

$k_4 = 3.66.$

This IC is used directly in calculating daily values of the MC0I, and weighted with a rain-influenced IC for calculating the daily LOI (section titled "Lightning Risk Model and Lightning Occurrence Index").

Man-Caused Risk Model

Jackson (1977) presented a model for predicting the average number of reportable man-caused fires for a given ignition component value:

$$E(\text{number of fires}) = IC(d)(d_1)(d_2)(A) \quad (85)$$

where d, d_1, and d_2 are empirically derived coefficients that tune the model to a particular protection unit, and A is the protection unit area in millions of acres. Jackson developed the model using fire occurrence data from Forest Service Region 9 (Eastern). Data from Region 3 (Southwest) were used for testing the model. The reported R^2 value was 0.89 for the tested area.

Equation 85 is normalized to millions of acres by dividing by A:

$$E(\text{number of fires}/10^6 \text{ acres}) = IC(d)(d_1)(d_2). \quad (86)$$

The MCOI is scaled such that 10 fires per million acres results in an MCOI value of 100, or:

$$MCOI = 10\ E(\text{number of fires}/10_6 \text{ acres}) \quad (87)$$

Combining equations 86 and 87 yields

$$MCOI = 10(IC)(d)(d_1)(d_2) \quad (88)$$

and by letting $d_o = 10d$, the expression becomes:

$$MCOI = IC(d_o)(d_1)(d_2). \quad (89)$$

But the desired final form of the equation is

$$MCOI = IC(R_{MC}/100) \quad (90)$$

so combining equations 89 and 90 yields:

$$MCOI = IC(d_o)(d_1)(d_2) = (IC)(R_{MC})/100. \quad (91)$$

Table 11.—Normalization constants for probability of ignition as a function of moisture of extinction and heat of ignition

Moisture of extinction (m_X, %)	Heat of ignition (Q_{ige}, Btu)	Constants			
		k_3	k_4	P_1	P_2
15	268	0.082164	2.58	0.01553	0.98446
20	306	.008379	3.15	.00554	.99446
25	344	.000932	3.66	.00232	[1].99767
30	381	.000120	4.11	.00050	.99950
35	425	.0000124	4.58	.00072	.99928
40	470	.00000135	5.02	.00052	.99948

[1]Used in the 1978 NFDRS IC.

Solving for R_{MC} yields:

$$R_{MC} = 100(d_o)(d_1)(d_2). \quad (92)$$

Coefficients d, d_o, d_1, and d_2 are area and unit (Region, Forest, or District) dependent. A Regional scaling factor, d, equals the historical number of man-caused fires per million acres, per day, per unit of ignition component for an entire region over a 5-year base period. Expressed numerically, it equals the slope of the regression (forced through zero) of the number of fires per million acre-days on the daily IC for the parent (regional) unit. An acre-day is the acreage of the regional protection unit multiplied by the number of fire-weather days in the 5-year analysis. The parent protection unit should be at least 10 million acres in size, with 300 or more man-caused fires per year. Recalling that:

$$d_o = 10d$$

d_o will generally range between 0.05 and 1.00.

d_1, a man-caused risk scaling factor, accounts for differences in risk between the parent unit (Region) and the protection unit (Forest or District). It serves as an input to both the AFFIRMS and FIRDAT processors.

d_1 is the ratio of the total number of fires on the protection unit divided by the product of the average IC value, area of the protection unit (10^6 acres), and the number of fire-weather days, all divided by the total number of fires on the parent unit divided by the product of the average IC value and the total acres in the parent unit and the total number of fire-weather days in the parent unit.

$$d_1 = \frac{\sum (\text{fires}_u)/IC_u\ A_u\ n_u)}{\sum (\text{fires}_r)/(IC_r\ A_r\ n_u)} \quad (93)$$

where

subscripts u and r denote the protection unit and parent region, respectively,

(fires) is the total number of man-caused fires for the computational period,

IC is the average daily IC (man-caused) for the period,

A is the area in millions of acres, and

n is the total days used in computing the IC values.

A correction factor, d_2, flows from a subjective evaluation of the activity level of the principal risk sources of man-caused fires on a protection unit. d_2 is partitioned by day of the week and the eight statistical fire causes available from standard fire report forms. d_2 adjusts for short-term fire problems (such as arson) or predictable changes in man-caused risk (weekend, holidays, hunting season, etc.):

$$d_2 = d_j/25 \quad (94)$$

where d_j is the unnormalized R_{MC} defined by:

$$d_j = \sum_{i=1}^{8} R_{ij} \quad (95)$$

where R_{ij} is the partial man-caused risk of source i (of the eight standard statistical fire causes) on day j of the week, and

$$R_{ij} = R_{SRij}G_{ij} \quad (96)$$

where R_{SRij} is the risk source ratio for day j of the week.

$$R_{SRij} = 7 \sum_{i=1}^{8} \sum_{j=1}^{7} \text{fires}_{ij}/\text{fires}_u \quad (97)$$

and G_{ij} is the risk (number of firebrands) associated with the daily activity level assigned by the fire manager to risk source i on day j.

Values of G for daily activity levels are presented in the following tabulation:

Daily activity level	G_{ij}
Extreme	100
High	50
Normal	25
Low	12
None	0

Deeming and others (1977) and Burgan and others (1977) detail computation of d, d_o, d_1, and d_2, burying most of the arithmetic in nomograms.

Man-caused risk (R_{MC}) determined from nomograms is used to calculate the daily MCOI from equation 90:

$$MCOI = (IC)R_{MC}/100. \quad (98)$$

The average number of fires for the protection unit then becomes

$$E(\text{number of fires}) = (MCOI)A(\text{millions of acres})/10. \quad (99)$$

APPLYING MAN-CAUSED RISK

The severity of man-caused fire problems on a protection unit dictates the level of man-caused risk assessment. For example, a complete analysis, with eight risk sources and a separate set of daily risk source ratios, R_{ij}, for each month may be needed for high man-caused fire areas such as southern California or southern Georgia. At the other extreme, managers of areas such as White Mountain National Forest in New Hampshire, which averages fewer than 10 fires per year, gain little by partitioning risk source ratios. In such situations all risk sources may be combined and it will be an unnecessary complication to stratify by day of week, month, or even season. Between the two extremes lies an approach that can tailor man-caused risk assessment to match the magnitude of the problem.

Lightning Risk Model and Lightning Occurrence Index

The lightning occurrence index (LOI) is an average estimate of the number of reportable lightning-caused fires per million acres protected:

$$LOI = IC_W R_L \quad (100)$$

where IC_W is the day's weighted lightning-caused ignition component, and R_L is an estimate of fire-starting lightning strikes in a rating area.

The 1978 NFDRS lightning-caused fire occurrence index model is based on an approach described by Fuquay and others (1979). The development of the LOI departed from Fuquay's model at the point where the probability of ignition of a lightning-caused fire is computed. For the sake of simplicity, the 1978 NFDRS IC was used

rather than Fuquay's P(I). The two methods were compared, and the resulting difference was judged to be within the range of uncertainty of the Fuquay model.

Lightning-caused risk (R_L) is a function of several meteorological parameters grounded in the lightning activity level (LAL). R_L is calibrated to a locality by a lightning risk scaling factor (K), which compensates for not using the Fuquay lightning ignition model. The lightning risk scaling factor is empirically derived from archived lightning-caused fire occurrence and lightning activity level data. The lightning risk scaling factor is required because of the differences between local fuel types in their susceptibility to ignition by lightning. Thunderstorms, amounts of rain, and lightning discharge characteristics also differ among regions. The Fuquay lightning ignition model was derived using thunderstorm data from northwestern Montana and northern Idaho.

The LAL is an index (forecasted, observed, and verified) of thunderstorm activity on a scale from 1 to 6 for a 2,500-mi^2 rating zone. Table 12 tabulates typical thunderstorm attributes for the six LAL's. Four typical storm characteristics have been designated for each LAL from 2 through 5. Lightning level 1 signifies no thunderstorms, and LAL 6 indicates a special condition involving high-level dry thunderstorms.

Table 12.—Thunderstorm attributes for lightning activity levels (adapted from Fuquay and others 1979)

Lightning activity level	Clouds and storm development	Rel. freq. on T/S days (%)	Fraction of area covered by radar echoes of indicated strength: Very light	Light	Moderate	Heavy	Percent of area receiving less than the amount of rain indicated: O-T	<0.1"	<0.3"	<0.9"
	Typical Cloud and Precipitation Conditions (2,500 mi^2 or 6 500 km^2 area)									
1	No thunderstorms[1]		No radar echoes				No precipitation			
2	Few building cumulus only occasionally reaching cumulus congestus stage; single cumulonimbus in forecast area. Visual tops: <30,000 ft (9 100 m) m.s.l.	10	0.1	<0.1			90	91	100	
3	Scattered cumulus to cumulus congestus; widely scattered cumulonimbus clouds; cloud-to-ground lightning averaging 1-2 per min max.	35	.2	.2	0.05		70	90	98	100
4	Growing cumulus and cumulus congestus stage over 0.1-0.3 of the area; scattered cloud-to-ground lightning in area averaging 2-3 per min max.	35	.2	.1	.05		65	80	95	100
5	Cumulus congestus common over area, occasionally obscuring the sky; moderate to heavy rain associated with cumulonimbus clouds light to moderate rain preceding and following lightning activity. Lightning flashes occurring steadily at some place in or during storm period; maximum cloud-to-ground flash rate greater than 3 per min.	18	.3	.1	.05	0.02	50	75	85	100
6	Scattered towering cumulus with a few at thunderstorm stage; very limited horizontal extent; high bases (15,000 to 17,000 ft m.s.l.). Virga in most prominent hydrometeor form. Lightning flash rate is low, averaging less than 1-3 per 5-min period each storm.[2].	<2								

Lightning - Amount and Rate

Lighting activity level	Maximum radar echo height, m.s.l.: Feet	Meters	Cloud-to-ground (CG) lightning per 2,500 mi^2 (6 500 km^2	Occurance rates, maximum: CG/5 min	CG/15 min	Ave. rate/min
2	<28,000	<8,500	20	—	—	—
3	26,000-32,000	7,900-9,700	40	0-10	0-17	1-2
4	30,000-36,000	9,100-11,000	80	4-19	6-32	2-3
5	>36,000	>11,000	160	9-32	19-77	3

[1]In most general terms, 2 days out of 3 will not be thunderstorm days during a typical fire season in the mountainous areas of the western continental United States

[2]Used with red-flag warnings of extreme fire activity.

LAL 6 conditions, although rare (fewer than 2 percent of thunderstorm days), often present extremely severe fire problems. They occur when sufficient moisture and instability for thunderstorm development are found only upwards from approximately 15,000 feet (mean sea level). Virtually no wetting precipitation reaches earth (it evaporates—often producing strong and erratic downdrafts), but lightning is still present. When an LAL of 6 is forecast, a red flag or equivalent alert is usually issued. For NFDR purposes R_L and LOI are both set at 100.

The four storm characteristics grounded in LAL's 2 through 5 are:

1. Number of cloud-to-ground lightning discharges per storm (S_{cg}),
2. Ground area covered by radar echoes—rain area (s_s),
3. Area intensity of rainfall, and
4. Total storm size (s_{dl}).

Forming an idealized storm (fig. 15), these and other parameters allow calculation of total cloud-to-ground lightning strikes over a rating area. The racetrack with an infield concept pictures a large lightning area encompassing a smaller rain and lightning area. This storm moves according to upper level winds (u_w) and rain falls over a fraction of the total storm area. The probability of ignition, P(I), is reduced in the rainfall area due to wetting of fine fuels. Table 13 depicts typical storm characteristics by lightning activity level. The adaptation of the model to the 1978 NFDRS assumes a constant storm speed of 30 miles per hour (u_w = 30) in the computation of other storm attributes.

Precipitation duration (p_d) is computed from the length of the rainfall band (s_s, mi) and the rate of storm movement (u_w):

$$p_d = s_s/u_w. \tag{101}$$

Storm duration (s_d) is computed from an empirically derived function dependent on cloud-to-ground strikes (S_{cg}):

$$s_d = -86.83 + 153.41(S_{cg})^{0.1437}. \tag{102}$$

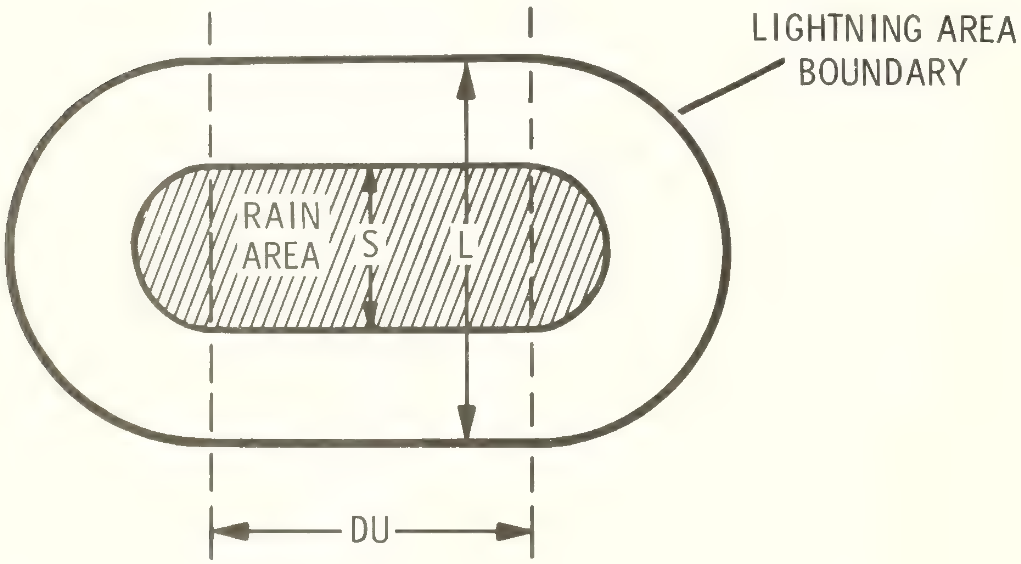

Figure 15.—Idealized shape of lightning and rain areas from a thunderstorm (from Fuquay and others 1979).

Table 13.—Storm characteristics by lightning activity level

Attribute	Lightning activity level					
	1	2	3	4	5	6
Cloud-to-ground discharge lightning strikes (strikes/2,500 mi²)	0	12.5	25	50	100	N/A
Rain corridor length (mi)	0	3	4	5	7	N/A
Lightning corridor length (mi)	0	7	8	9	11	N/A

Simple geometry defines the fractional areas with (f_w) and without (f_o) rainfall:

$$f_w = (4s_du_ws_s + \pi s_s^2)/(4s_du_ws_{dl} + \pi s^2{}_{dl}) \qquad (103)$$

$$f_o = 1 - f_w. \qquad (104)$$

Fine fuel moisture (1-hour timelag) within the rain area is adjusted using a modified 1-hour timelag fuel moisture diffusion equation:

$$mc_{1r} = mc_1 + (d_{ef} - mc_1)(1 - \zeta \exp(-T/\tau)). \qquad (105)$$

For 1-hour fuel, $1 = \zeta = \tau$; thus

$$mc_{1r} = mc_1 + (d - mc_1)(1 - \exp(-T)) \qquad (106)$$

where

mc_{1r} is the fine fuel moisture in the rain area,
mc_1 is the computed 1-hour fuel moisture,
T is the storm precipitation duration ($T = p_d$), and
$d = (76.0 + 2.7p_d)$—see 10-hour fuel section.

Heat of preignition (eq. 76) is computed for the wetted area using ambient fuel temperature and mc_{1r} as independent variables.

Probability of ignition, P(I), and ignition component for the rain area (IC_I) are then computed from equations 80 through 84 as in the MCOI.

A weighted lightning ignition component (IC_W) is then computed using the rain fractional area and its associated ignition component (IC_I), and the nonrain fractional area and the IC computed for man-caused occurrence index (IC):

$$IC_w = [f_w(IC_I) + f_o(IC)]/100 \qquad (107)$$

where both IC_I and IC are upwardly limited at 100.

If a general rain is noted on the fire-weather observation (or forecast), IC_W is set to zero.

LIGHTNING STRIKES

A cloud-to-ground (CG) lightning strike consists of several sequential events. In about 20 percent of these CG flashes an extended return stroke, or a "long continuing current" (LCC) is present. Fuquay and others (1967, 1972) have shown that this LCC stroke is highly likely to ignite most lightning-caused fires. Therefore, R_L is modified to include only LCC lightning events:

$$R_L = 0.20(S_{cg})(R_L)(K_1) \qquad (108)$$

where

S_{cg} is the total number of lightning strokes, R_L is the local scaling factor, and

K_1 is a factor used to scale the predictions to strikes per million acres (model was developed on Nezperce and Clearwater National Forests in the Northern Region and $K_1 = 1.5$).

A second factor (K_2) is used to scale R_L such that when:

LAL = 5
$R_L = 1$
$K_1 = 1.5$
$IC_W = 100$

R_L will equal 100. Recalling that when LAL = 5, $S_{cg} = 100$, and including K_2, equation 108 becomes

$$100 = K_2(0.20)(100)(1)(K_1). \qquad (109)$$

Solving for K_2 yields $K_2 = 5/K1 = 3.33$. Inserting these back into the R_L equation:

$$R_L = K_2(0.20)(S_{cg})(K) \qquad (110)$$

yields the number of LCC discharges, per million acres, scaled to a local protection unit.

The lightning occurrence index is then calculated from:

$$LOI = [10R_L(IC_W)] + 0.25(LOI_y) \qquad (111)$$

where

the multiplier 10 scales LOI to 100 when 10 fires per million acres are predicted,
R_L is the number of LCC discharges (locally scaled),
IC_W is the weighted ignition component, and
$0.25(LOI_y)$ is a persistence function to help account for carryover from the previous day's LOI (LOI_y).

The lightning risk scaling factor is empirically derived as follows:

$$K = \frac{10 \sum_{u=1}^{u=N} fires_u}{1.6 \sum_{u=1}^{u=N} LOI_u} \qquad (112)$$

over a recent 3- or 4-year period. The K is then adjusted every 5 years:

$$K_{new} = \frac{10\ K_{old} \sum_{u=1}^{u=N} fires_u}{A \sum_{u=1}^{u=N} LOI_u} \qquad (113)$$

where A is the rating area in millions of acres, and fires and LOI are as defined before except they are for later periods (see Deeming and others 1977 for more complete operational examples).

THE FIRE LOAD INDEX

The fire load index measures the total potential containment effort that may be needed on a given day. It combines the containment effort for a single fire (burning index), with the average number of expected fires:

$$FLI = \sqrt{(BI^2 + (MCOI + LOI)^2)}/1.41 \qquad (114)$$

where the BI, and the sum of MCOI and LOI, are limited to a maximum value of 100. The normalizing factor of 1.41 limits the FLI to a maximum value of 100.

VARIABLES AND SYMBOLS

Variable	Description
A	Area (ft^2, m^2)
A_1	Age correction function for aging fuel sticks
A_i	Mean total surface area of ith category per unit fuel cell
$\bar{A}_{ij}$	Mean total surface area of jth class and ith category per unit cell
$\bar{A}_T$	Mean total surface area per unit fuel cell
a	Age of fuel moisture sticks (days)
a_h	Y-intercept on live fuel regression
a_w	Y-intercept of woody fuel moisture regression
B	Secondary fuel stick aging function
B_I	Burning index (dimensionless)
b_h	Slope on live fuel regression
b_w	Slope of woody fuel moisture regression
C	Climate class dependent fuel stick aging function
C_c	1978 NFDRS climate class
D	Daily equilibrium moisture content boundary conditions for 100-hour fuel moisture computations, %
D_n	Period boundary moisture conditions for forecast 10-hour fuel moisture or 1,000-hour computations, %
d	Regional scaling factor (dimensionless)
d_o	10d
d_1	Man-caused risk scaling factor (dimensionless)
d_2	Correction for risk sources (dimensionless)
d_j	Unnormalized man-caused risk for the jth day of the week (number of person-caused firebrands/million acres)
EMC	Equilibrium moisture content, %
ERC	Energy release component (dimensionless)
f_i	Surface area weighting parameter I (dimensionless) ratio of surface area of ith category to total surface area, per unit fuel cell
F_L	Flame length (ft)
FLI	Fire load index (10 × number of fires/million acres)
F_o	Fourier number (dimensionless)
f_o	Fractional area of thunderstorm without rainfall
f	Fraction of herbaceous fuel to be transferred to 1-hour class
f_w	Fractional area of thunderstorm with rainfall
f_{ij}	Surface area weighting parameter II (dimensionless) ratio of surface area of jth size class to total surface area of ith category, per unit fuel cell
G_{ij}	Man-caused risk (number of firebrands) associated with the daily activity level
gu	Elapsed fraction of green-up period
H	Heat content (Btu/lb)
IC	Ignition component (dimensionless)

Variable	Description
IC_W	Rainfall area weighted ignition component (dimensionless)
I_R	Surface area weighted reaction intensity (Btu/ft^2-min)
I_{Re}	Load weighted reaction intensity (Btu/ft^2-min)
J	Julian date
K	Lightning risk scaling factor (dimensionless)
K_1	Lightning area scaling factor I (dimensionless)
K_2	Lightning area scaling factor II (dimensionless)
k_1	Drying or wetting factor in live moisture model
k_2	Temperature factor in live moisture model (dimensionless)
k_3	Calibration constant for computing P(I) (dimensionless)
k_4	Calibration constant for computing P(I) (dimensionless)
L	Length (ft, m)
LAL	Lightning activity level (dimensionless)
LOI	Lightning-caused occurrence index (number/million acres)
LOI_y	Yesterday's lightning-caused occurrence index (number/million acres)
MCOI	Man-caused occurrence index (man-caused fires/10^6 acres)
m_f	Fuel moisture content (fraction)
m_{fw}	Weighted "fine" dead fuel moisture (fraction)
m_x	Moisture of extinction, %
m_{xd}	Dead fuel moisture of extinction, %
m_{xl}	Live fuel moisture of extinction, %
mc	Ratio of characteristic fuel bed moisture content to dead or live fuel particle moisture of extinction
mc_h	Live herbaceous fuel moisture, %
mc_w	Woody fuel moisture content, %
mc_1	1-hour timelag fuel moisture content, %
mc_{10}	10-hour timelag fuel moisture content, %
mc_{10k}	Age-corrected fuel stick moisture content, %
mc_{100}	100-hour timelag fuel moisture content, %
mc_{1000}	1,000-hour timelag fuel moisture content, %
P(I)	Probability of ignition
P_1	Probability coefficient for P(I) calculations
P_2	Second probability coefficient for P(I) calculations
p_a	Daily precipitation amount (inches)
p_d	Precipitation duration (h)
p_{d1}	Precipitation duration for first forecast period (h)
p_{d2}	Precipitation duration for second forecast period (h)
p_r	Precipitation rate (inches/h)

VARIABLES AND SYMBOLS (con.)

Variable	Description
Q_{ig}	Heat of preignition (Btu/lb fuel)
Q_{ige}	Effective heat of preignition (Btu/lb fuel)
Q_{igmx}	Minimum heat for ignition (Btu/lb fuel)
R	Rate of fire spread (ft/min, cm/s)
R_l	Number of fire-starting lightning strikes in a rating class
R_L	Lightning-caused risk (number fire-starting strikes/million acres)
R_{MC}	Man-caused risk (man-caused firebrands/million acres)
R_{SRij}	Risk source ratio for man-caused risk sources for the ith source on the jth day
r	Radius (ft)
S_{cg}	Number of cloud-to-ground lightning strikes per 2,500 mi^2
S_e	Effective mineral content (lb silica-free minerals/lb ovendry fuel)
S_t	Total mineral content (lb minerals/lb ovendry fuel)
SC	Spread component (dimensionless)
SC_{max}	Maximum probable spread component (dimensionless)
SC_N	Spread component, normalized by maximum probable value (dimensionless)
s_d	Thunderstorm duration (h)
s_{dl}	Total storm length (with and without rain, mi)
s_s	Rainfall path length (mi)
s_1	Lightning area scaling factor I (dimensionless)
s_2	Lightning area scaling factor II (dimensionless)
T	Moisture stress simulation time step (h)
T_F	Fuel temperature (°C)
T_{ig}	Ignition temperature (°C)
u_w	Thunderstorm movement speed (mi/h)
V_b	Fuel bed total volume (ft^3, cm^3)
V_f	Fuel bed fuel volume (ft^3, cm^3)
V_v	Fuel bed void volume (ft^3, cm^3)
W	Dead-to-live loading ratio
W_f	Weight of fuel moisture sticks (g)
W_h	Total herbaceous fuel load (lb/ft^2; tons/acre)
W_{hg}	Load of herbaceous fuel that is still green (lb/ft^2; tons/acre)
W_{ij}	Net fuel load (for live fuels, i=2 and j indicates 1-hour, 10-hour, or 100-hour timelag class; for dead fuels, i=1 and j indicates 1-hour, 10-hour, or 100-hour timelag class)
W_n	Net fuel mass (total fuel mass less inorganic mass, lb/ft^2; tons/acre)
W_o	Total fuel mass (lb/ft^2; tons/acre)
W_{1h}	Load of 1-h prior to inclusion of herbaceous fuels (lb)
W_{1hd}	Total 1-hour load including dead herbaceous (lb/ft^2; tons/acre)
X_{1000}	Live fuel moisture recovery value, %
X_{y1000}	Yesterday's live fuel moisture recovery value, %
overbar	Mean value for any indicated variable

Greek Symbol	Description
α	Fraction of living fuel to dead in a fuel bed
α_d	Angle of daylight (degrees, converted to radians)
β	Packing ratio (dimensionless)
χ	Probability of ignition subfunction
χ_s	Fuel particle shape factor
δ	Fuel bed depth (ft, m)
δ_d	Angle of solar declination (degrees, converted to radians)
$\Delta\mu$	Potential moisture content change during stress period, %
$\delta\mu$	Actual moisture content change during stress period, %
Δmc_{1000}	24-hour change in the 1,000-hour moisture content, %
η	Moisture-damping coefficient for spread component
η_e	Moisture-damping coefficient for energy release component
μ	Relative moisture content, %
ν	Diffusivity (cm^2/s)
σ	Fuel bed porosity (dimensionless)
σ_L	Fire-weather station latitude (degrees)
σ_s	Slope factor
$\sigma\psi$	Wind factor
ϱ_b	Fuel bed density (lb/ft^3, g/cm^3)
ϱ_p	Fuel particle density (lb/ft^3, g/cm^3)
σ	Surface area-to-volume ratio (1/ft, 1/cm)
τ	Fuel particle timelag (h)
τ_r	Flaming residence time (min)
ζ	Timelag similarity coefficient (dimensionless)

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APPENDIX A: ORGANIZATION AND LOCATIONS OF NFDRS PROJECTS

The National Fire-Danger Rating System research work unit was organized in 1968 by the U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colo. It consisted of the following scientists: Mark J. Schroeder, project leader; Michael A. Fosberg, research meteorologist; and James W. Lancaster, forester.

In the spring of 1970, Schroeder returned to the fire meteorology project at the Riverside Fire Laboratory, Riverside, Calif. James W. Lancaster became project leader and John E. Deeming joined the project, relocating from the Southern Forest Fire Laboratory at Macon, Ga.

Other persons eventually involved included R. William Furman, meteorologist; David Rainey, forest resource technician; and Bruce McCammon, forest resource technician.

In 1973, Lancaster and Deeming relocated to the Boise Interagency Fire Center (BIFC), and in 1974 were joined by Robert J. Straub, computer specialist.

In 1975, the fire-danger research work unit was relocated under the Intermountain Forest and Range Experiment Station at the Northern Forest Fire Laboratory in Missoula, Mont. The research work unit was led by John Deeming, with assistance from research foresters Robert E. Burgan and Jack D. Cohen.

The 1971 NFDRS was initially tested on the following National Forest System units:

Arizona: Tonto, Gila, and Coronado National Forests.

California: Klamath National Forest.

Idaho: Boise National Forest.

Montana: Lolo National Forest.

New Mexico: Carson National Forest.

Wyoming: Medicine Bow National Forest.

Additionally, it was tested on the Chiricahua and Saguaro National Monuments in Arizona; the Shoshone, Idaho, District of the Bureau of Land Management; and finally, by the Georgia State Forestry Commission.

APPENDIX B: FUEL MODELS

Sections titled "Forest Fuels" and "Fuel Models" in the main text defined eight fuel parameters required to completely describe a fuel complex for fire modeling purposes. These parameters are:

1. H - heat content, Btu/lb,
2. π_p- fuel particle density, lb/ft^3,
3. S_t - total mineral content, %,
4. S_e - effective mineral content, %,
5. W_o - total fuel load, lb/ft^2,
6. δ - fuel bed depth, ft,
7. σ - surface area to volume ratio, l/ft, and
8. m_x - moisture of extinction, %.

The section titled "Spread Component" described the use of wind reduction factors used to reduce the 20-foot windspeed to the midflame windspeed required for solution of the fire spread model, and the section titled "Ignition Component" discussed the maximum probable spread component used in computing the ignition component. For calculating SC_{max}, each fuel model was run through the fire model with these parameter conditions:

1-hour fuel moisture	4%
10-hour fuel moisture	6%
100-hour fuel moisture	8%
1,000-hour fuel moisture	11%
Herbaceous fuel moisture	65%
Woody fuel moisture	75%
Windspeed (20-ft)	20 mi/h
1978 NFDRS slope class	1 (22.5% slope)
1978 NFDRS climate class	3

Table 14 delineates the physical attributes of the fuel models on the 1978 NFDRS.

Table 14.—Physical attributes of each of the fuel models on the 1978 National Fire-Danger Rating System

Attribute	Fuel Model																			
	A	B	C	D	E	F	G	H	I	J	K	L	N	O	P	Q	R	S	T	U
Load (tons/acre)																				
1-hour dead	0.2	3.5	0.4	2.0	1.5	2.5	2.5	1.5	12.0	7.0	2.5	0.25	1.5	2.0	1.0	2.0	0.5	0.5	1.0	1.5
10-hour dead	—	4.0	1.0	.5	2.0	2.0	2.0	1.0	12.0	7.0	2.5	—	1.5	3.0	1.0	2.5	.5	.5	.5	1.5
100-hour dead	—	.5	—	—	.25	1.5	5.0	2.0	10.0	6.0	2.0	—	—	3.0	.5	2.0	.5	.5	—	1.0
1,000-hour dead	—	—	—	—	—	—	12.0	2.0	12.0	5.5	2.5	—	—	2.0	—	1.0	—	.5	—	—
Woody	—	11.5	.5	3.0	.5	9.0	.5	.5	—	—	—	—	2.0	7.0	.5	4.0	.5	.5	2.5	.5
Herbaceous	.3	—	.8	.75	.5	—	.5	.5	—	—	—	.5	—	—	.5	.5	.5	.5	.5	.5
Surface-area-to-volume ratio (1/ft)																				
1-hour dead	3,000	700	2,000	1,250	2,000	700	2,000	2,000	1,500	1,500	1,500	2,000	1,600	1,500	1,750	1,500	1,500	2,500	2,500	1,750
10-hour dead	—	109	109	109	109	109	109	109	109	109	109	—	109	109	109	109	109	109	109	109
100-hour dead	—	30	—	—	30	30	30	30	30	30	30	—	—	30	30	30	30	30	—	30
1,000-hour dead	—	8	—	—	—	—	8	8	8	8	8	—	—	8	—	8	—	8	—	—
Woody	—	1,250	1,500	1,500	1,500	1,250	1,500	1,500	—	—	—	—	1,500	1,500	1,500	1,200	1,500	1,200	1,500	1,500
Herbaceous	3,000	—	2,500	1,500	2,000	—	2,000	2,000	—	—	—	2,000	—	—	2,000	1,500	2,000	1,500	2,000	2,000
Heat content (all fuels) (Btu/lb)	8,000	9,500	8,000	9,000	8,000	9,500	8,000	8,000	8,000	8,000	8,000	8,000	8,700	9,000	8,000	8,000	8,000	8,000	8,000	8,000
Moisture of extinction (%)																				
Dead	15	15	20	30	25	15	25	20	25	25	25	15	25	30	30	25	25	25	15	20
Fuel bed depth (ft)	.8	4.5	.75	2.0	.4	4.5	1.0	.3	2.0	1.3	.6	1.0	3.0	4.0	.4	3.0	.25	.4	1.25	.5
SC_{max}	301	58	32	68	25	24	30	8	65	44	23	178	167	99	14	59	6	17	96	16

Constant fuel particle values for all fuels:

Fuel particle density (π_b):	32 lb/ft^3
Total mineral content (S_t):	0.0555
Effective mineral content (S_e):	0.01

APPENDIX C: EQUILIBRIUM MOISTURE CONTENT

Equilibrium moisture content (EMC) is an important aspect of the NFDRS dead fuel moisture models. The EMC is the moisture content (%) of a fuel particle allowed sufficient time to reach equilibrium with its environment (no net moisture exchange). EMC calculations are functions of temperature and relative humidity and are computed from regression equations developed by Simard (1968). Simard used tables from the Wood Handbook published by the U.S. Department of Agriculture, Forest Service, in 1955, revised 1974, as the basis for his equations. The equations for equilibrium moisture content are:

$$EMC = \begin{cases} 0.03299 + 0.281073h - 0.000578hT & h < 11 \quad \text{(C-1)} \\ 2.22749 + 0.160107h - 0.01478T & 10 < h < 51 \quad \text{(C-2)} \\ 21.06060 + 0.005565h^2 - 0.00035hT - 0.483199h & h > 50 \quad \text{(C-3)} \end{cases}$$

where

h is the fuel-atmosphere interface relative humidity (%),

T is the fuel-atmosphere interface temperature (°F), and

EMC is the fuel particle equilibrium moisture content (%).

APPENDIX D: WEIGHTING 24-HOUR BOUNDARY CONDITIONS BY DAY LENGTH

Latitude, date, and the earth's angle of declination in its orbit about the sun control day length cycles. In calculating the 100-hour and 1,000-hour fuel moisture, day length is used to weight the 24-hour maximum and minimum EMC's to compute the boundary EMC.

The day's maximum EMC is estimated from the minimum temperature and maximum relative humidity (assumed to occur simultaneously at night). Minimum EMC is computed from the day's minimum relative humidity and maximum temperature (assumed to occur simultaneously during the day).

These values are then weighted by the hours of either nighttime or daytime and averaged for the 24-hour period:

$$EMC_{24} = (h_d EMC_{max} + h_l EMC_{min})/24 \qquad \text{(D-1)}$$

where h_d and h_l are hours of dark and hours of daylight, respectively. Hours of daylight are computed from station latitude and date of observation.

For the following discussion, refer to figure 16. The day's angle of solar declination (δ) is computed from:

$$\delta = (23.5)\sin(k(J - 82)) \qquad \text{(D-2)}$$

where

J = Julian date

k = degree/day constant (0.9863 ≅ 1.00), and

23.5 is the maximum solar declination (at the solstices).

The distance from the polar axis to the circle of illumunation is calculated from

$$Z = d(\tan \delta) \qquad \text{(D-3)}$$

where d is the distance from the equator to the latitude circle defined by the station latitude (ϕ), and r is the radius of the earth:

$$d = r \sin \phi \qquad \text{(D-4)}$$

$$S = r \cos \phi. \qquad \text{(D-5)}$$

Thus

$$Z = r \sin \phi \tan \delta \qquad \text{(D-6)}$$

and

$$\alpha = \cos^{-1} (Z/S). \qquad \text{(D-7)}$$

Substituting for S and Z

$$\alpha = \cos^{-1} \frac{r \sin \phi \tan \alpha}{r \cos \phi} \qquad \text{(D-8)}$$

which simplifies to

$$\alpha = \cos^{-1} (\tan \phi \tan \delta). \qquad \text{(D-9)}$$

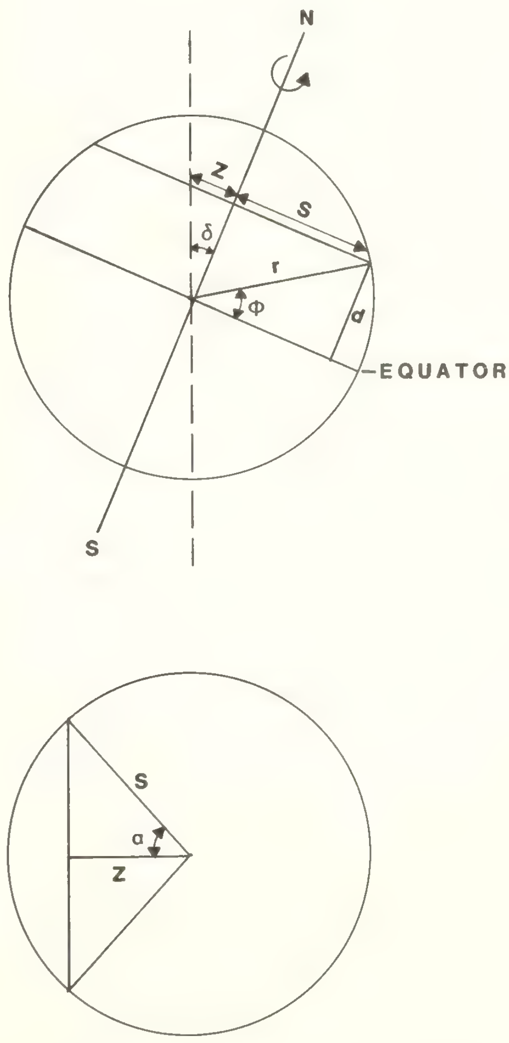

Figure 16.—Geometry for computing a day's angle of solar declination. The earth's axis is inclined 66.5° from the plane of orbit.

α is then proportional to day length. That is

$$h_l = 24h - 2\alpha \frac{24h}{2\pi} \quad \text{(D-10)}$$

where the angle measure is in radians.
Substituting for α, day length is

$$h_l = 24h\,(1-(\cos^{-1}(\tan\phi\tan\delta))/\pi) \text{ in hours} \quad \text{(D-11)}$$

Using the data from stations in Lytle Creek, Calif. (34° N), Libby, Mont. (48° N), and Fairbanks, Alaska (65° N), Burgan (1976) tested the effects of daylight) weighted boundary conditions on the MCOI, BI, and ERC indexes of the 1978 NFDRS.

Day length has little effect on MCOI and BI because they are most sensitive to the fine fuel moisture content as expressed through the spread component (used in computation of both the MCOI and BI). Here daily values affect the fine fuel moistures more than seasonal trends.

The ERC, on the other hand, is strongly influenced by the moisture contents of the heavier 100-hour and 1,000-hour fuels, which are affected by seasonal drying trends. Figures 17, 18, and 19 illustrate these differences.

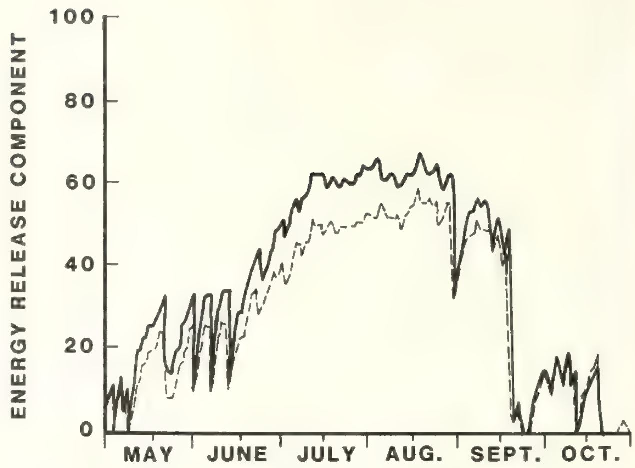

Figure 18.—Energy Release Component computed for Libby, Mont. (latitude 48° N, 1973 data), with a constant day length value (dotted lines) and with variable day length (solid line) (from Burgan 1976).

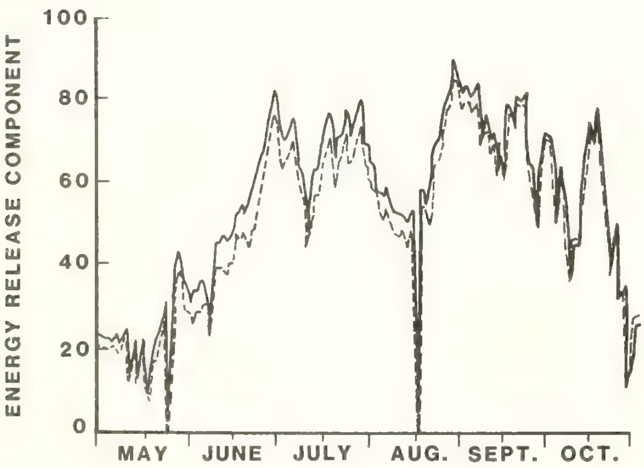

Figure 17.—Energy Release Component computed for Lytle Creek, Calif. (latitude 34° N, 1974 data), with a constant day length value (dotted line) and with variable day lengths (solid lines) (from Burgan 1976).

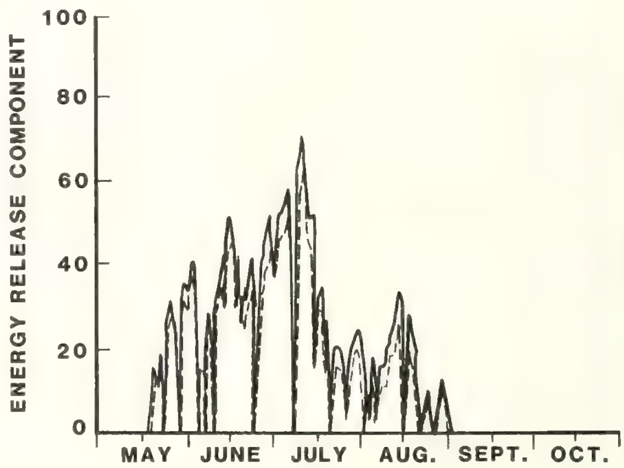

Figure 19.—Energy Release Component computed for Fairbanks, Alaska (latitude 65° N, 1975 data) with a constant day length value (dotted lines) and with variable day length (solid lines) (from Burgan 1976).

APPENDIX E: REFLECTIONS ON THE DEVELOPMENT, APPLICATION, AND FUTURE OF THE NATIONAL FIRE-DANGER RATING SYSTEM

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Introduction

Five years have passed since the NFDRS was updated (Deeming and others 1977). I remain interested in and am frequently consulted about the general subject of fire-danger rating and the NFDRS specifically. What follows are my views of the NFDRS—its technical adequacy, its use, and the obstacles to overcome to improve utilization of the 1978 or any future version of the System.

The NFDRS has some technical flaws. The development team was working against a deadline, and therefore utilized existing technology or the technology that could be developed in the time available. Our "best guess" prevailed when all else failed. I am convinced, however, that the usefulness of the System is not compromised by technological "splints", but by inappropriate application.

System Administration

NFDRS APPLICATIONS

Fire managers expected, and in most instances still expect, the NFDRS to provide the high spatial and temporal resolution of a fire behavior prediction system. Fire-danger rating areas are typically greater than 100,000 acres and the weather is observed and predicted for **one specific time** during the day at **one specific location.** Using this "worst case" approach reduces the uncertainty concerning the meaning of a rating derived from such a modest sampling effort.

Many decisions made at the different administrative levels of fire management have not been carefully analyzed and the requirements of supporting information have not been developed. Managers must recognize that the scale of the information used in making a decision must match the scale of that decision. The NFDRS was designed for low resolution, medium-to-large-scale applications; the Fire Behavior System (FBS) (Rothermel 1983) was designed for high resolution, small-scale application.

We must all recognize that managing wildfires is much more complex than when the NFDRS development program began. Managed fires, natural prescribed fires, delayed initial attack, economic efficiency, and cost-plus-net-value change were not everyday considerations in fire control offices in 1968. The scope of the modern fire management job requires new approaches for using weather and fire-danger ratings. Techniques for blending the NFDRS and FBS have not been developed. What has happened? The NFDRS has been frequently misapplied and has been used where it has failed to provide the high resolution information needed by management. Such failures have stimulated unjustified criticism and have undermined the credibility of the System.

PREPAREDNESS CLASSES

The bottom line of fire-danger rating in the day-to-day operation of a fire program is the manning class. This is sometimes called the manning and specific action class, preparedness class, adjustive class, or precautions class. The idea is to divide the continuum of fire danger into discrete classes to which preplanned management actions are keyed. The designations for the classes are commonly numerical, I (one) through V (five); or adjective, Low through Moderate, High, and Very High to Extreme.

The NFDRS does not include the procedures for delineating preparedness classes; the NFDRS produces numerical indexes of the fire danger. Manning class definition is the fire manager's job and one that has not been done satisfactorily in most instances.

Manning classes should be based on incremental needs for specific levels of suppression action. For instance, using wildfire reports (Yancik and Roussopoulos 1982) and historical fire danger (Furman and Brink 1975; Main and others 1982), it could be determined at what level of fire danger the probability of failure of initial attack with hand crews is unacceptably high. That level of fire danger might then be designated Class III, and a retardant aircraft preplanned for dispatch on Class III days. There is little hope the NFDRS or any updated version of the NFDRS will be satisfactory in the eyes of fire managers until the manning class problem is resolved.

TRAINING

The NFDRS is a flexible, adaptable system. If the user understands the NFDRS technology, the unique requirements of the myriad of agencies can be served and the evolving range of fire management tasks supported. The situation facing management is that a continuing effort must be made to train new personnel as the ranks of experienced NFDRS users thin over time.

Training is a continuing requirement for the proper application of NFDRS. The NFDRS is not like a bell buoy anchored to a reef. The requirement for the bell buoy to provide visual and audio warnings of a navigation hazard does not change; the requirements for the information the NFDRS is capable of producing are constantly evolving. Hence, up-to-date, knowledgeable users are essential

Technical

INPUT DATA

Weather

Without a program that assures uninterrupted, quality weather observations, the System will not work. Fischer and Hardy (1976) published an excellent guide for setting up and maintaining weather stations and making observations. If this guide were followed, and provisions made for taking data every day starting 30 days before the ratings are needed, many of the difficulties with the NFDRS would disappear.

A network of weather stations designed around the NFDRS would decidedly improve predictions. Until 1980, however, such a system was not feasible because instruments had to be located where people were available to read and record data. With the development of solar-powered, automatic instrumentation, and satellite communications (Warren and Vance 1981), the "people" limitation no longer exists. The issue of weather station network design is now timely and is being pursued at both Rocky Mountain and Pacific Southwest Forest and Range Experiment Stations, Forest Sevice, U.S. Department of Agriculture (Furman 1975; King and Furman 1976).

The higher the density of weather stations, the more accurate the fire-danger information. Because weather stations are expensive to set up and operate, the design must be cost effective. What information is vital to the decision making process? How accurate must the fire-danger information be? Network design guidelines would enable users to get the most for their money. This returns us to a subject already addressed, the requirement for fire management to systematize decisionmaking.

Fuel Models

Fuel model selection must be based on the capabilities of the model to emulate seasonal trends of fire potential in a fire-danger rating area. The suitability of a fuel model is a function of how well the fuel classes and the relative proportions of those classes in the fuel model match what is on the ground. If it can be shown that none of the 20 available fuel models are suitable, efforts to improve or develop new models should be considered.

Before building new fuel models, however, one should be certain that is where the fault lies. A new fuel model will not eliminate poor performance in situations where the NFDRS is being applied incorrectly or there exists an inadequate weather observation program. A great deal of art is involved in the development and evaluation of fuel models. Guidelines and a training program are needed for fuel model developers.

DERIVED INPUTS

Dead Fuel Moisture Models

The unrealistic indication of the recovery of fire danger after a precipitation event is a serious shortcoming of the NFDRS in areas where the primary fuel is litter and duff. Contrary to the assumptions made in the System, the atmosphere is not the only moisture source/sink (as determined by measurement of the ambient relative humidity, temperature, and precipitation). The soil and duff, after a precipitation event, are a significant source of moisture for dead plant material in the forest floor.

Another factor contributing to the overrating of fire potential in forested areas is the way the atmospheric data that drive the dead fuel moisture models are collected and interpreted. In the United States, fire danger has always been evaluated at open sites: the practice is consistent with the "worst case" approach to rating fire danger. This may be the time to introduce some flexibility into our fire-danger rating policy and use in-stand conditions where open areas are atypical. The Canadians have done this for years for forested areas.

Evidence that the current dead fuel moisture predictive models can be improved comes from Forest Service research units at East Lansing, Mich. (Loomis and Main 1980; Simard and Main 1982; Simard and others, in preparation), Seattle, Wash. (Ottmar 1980), and Tempe, Ariz. (Harrington 1982). Better NFDRS fuel moisture models would greatly benefit prescribed burning and the fire behaviour prediction and fire management planning systems. The NFDRS fuel moisture predictions are used in those applications because the NFDRS is the only weather "bookkeeping system" available. Improved dead fuel moisture models would be easily incorporated into the NFDRS, but one must be careful to assess the "bottom line" effects on the ratings (see section titled "System Tuning").

Live Fuel Moisture Models

The critical step in applying the NFDRS where the condition of the live vegetation dominates the fire danger is the proper keying of the System's live fuel moisture models when new growth commences (Burgan 1979). It is a stated requirement that the NFDRS computations start a month before green-up, but that it seldom done in areas with a mid- to late-summer fire season.

The importance of responsive, accurate, live fuel moisture increases as the ratio of live-to-dead fuels in the fuel complex increases. In open hardwood and conifer forests, brush and chaparral, and range vegetation types, the live-to-deal fuel ratio is high; hence, live fuel moisture predictions must at least parallel actual conditions. The current models do a reasonable job if green-up is triggered on time and if the temperature adheres to a typical seasonal pattern.

What happens when conditions, principally the temperature, do not follow the typical seasonal patterns? The models do not work. How well or how poorly the current NFDRS live fuel models work has not been documented except for a study conducted in the Northeast by the Forest Service research group at East Lansing, Mich. (Loomis and Blank 1981). It is my view that new models incorporating temperature are required.

The NFDRS provides the option for directly entering live fuel moisture values, bypassing the models. The flammability of chaparral is very much a function of the moisture content of the foliage. In California, therefore, for years fuel moisture has been directly sampled. Because a general model for predicting the moisture content of live plants is unlikely, a foliage-sampling program may be warranted where the condition of live plants is very important to fire-danger rating

Drought

The effects of the intermediate-term (up to 6 weeks) meteorological drought is reflected by the NFDRS in both the live and dead fuel moisture predictions. Introduction of the live fuel model to account for curing of live herbaceous vegetation, and the 1,000-hour timelag class for large dead fuels in 1978 ameliorated a shortcoming the 1972 NFDRS, but it did not eliminate the drought problem in those areas where organic soils or very deep duff and litter are found. For those regions provisions must be made to incorporate a measure of

long-term meteorological drought such as that developed by Palmer (1965) or Keetch and Byram (1968).

Midflame Windspeed

In the NFDRS, the factors used to reduce the 20-foot standard windspeed to the midflame height depend on the fuel model and range from 0.6 for the "open" fuels to 0.4 for the "sheltered" fuels. Albini and Baughman (1979) have provided a better set of reduction factors that range from 0.1 to 0.6.

A great deal of "noise" in the fire-danger ratings is caused by the literal use of windspeeds in the lower (nonsignificant) speed ranges. Wind varies tremendously from point to point and from time to time. Windspeed measured at one point at one time is not necessarily a reliable indicator of the wind over a large fire-danger rating area.

I recommend that all winds less than 10 mi/h be treated as a constant 6 mi/h. Why 10 mi/h for the cutoff? The reasoning is that winds less than about 10 mi/h are dominated by local effects such as differential heating (Albini and others 1982). Above that windspeed, the odds are good that the wind field is being dominated by a meso- or synoptic-scale weather process that can be described and predicted.

THE FIRE-DANGER RATING PROCESSOR

Moisture of Extinction

The moisture of extinction is the fuel moisture level above which a fire will not spread. In the NFDRS the moisture of extinction varies by fuel model, ranging from a low of 15 percent in annual grasses to 40 percent in southern pine litter. Those values are supported, in some cases by studies (Brown 1972; Sneeuwjagt 1974; Bevins 1976; and Sneeuwjagt and Frandsen 1977), but they have been established subjectively for most fuel models. The fact is that the moisture of extinction not only varies between fuel types but also within fuel types as the windspeed and slope change. Also, the moisture of extinction for the initial igition is lower than the moisture of extinction for a going fire because of the limited energy contained in the typical firebrand.

Weighted (Characteristic) Fuel Moisture

In the Rothermel fire spread model (Rothermel 1972), the heterogeneous fuel (more than one fuel class in a fuel complex) situation is addressed by using a weighting process to calculate, for instance, a characteristic surface-area-to-volume ratio for the fuel complex. In the NFDRS, the weighting for the Spread Component is done exactly as Rothermel (1972) does, using as the basis of weighting the proportions of the total surface area of all fuels contributed by the individual fuel classes. For the Energy Release Component, the weighting is based on the contribution of the individual class load to the total load of the fuel complex. Weighting by surface area causes fire behavior to be underrated when the larger fuels are dry enough to burn, whereas weighting by loading causes the fire behavior to be underrated when the larger fuels are too wet to burn. Weighting by loading was introduced in the 1972 NFDRS and retained in the 1978 NFDRS to increase the influence of the condition of the larger fuels on the rating in the upper range of fire danger.

Using the weighted fuel moisture causes unrealistic ratings when the 100-hour and 1,000-hour timelag fuels have moisture contents well above the fixed dead fuel moisture of extinction. Put another way, even though the fine and intermediate fuels are dry enough to burn and carry fire, the NFDRS says "zero" because the weighted average fuel moisture exceeds the moisture of extinction. Experienced fire managers know that a fire will burn through one fuel stratum without involving the other fuel strata. The NFDRS should reflect that behavior.

SYSTEM TUNING

If changes are made to any of the items I have mentioned, the System will have to be recalibrated. The 1972 and 1978 versions of the NFDRS were subjectively tuned to compensate for limitations remaining in the component models. How is that done? The final tuning is done by manipulating the fuel model parameters until the ratings properly reflect conditions for selected cases (a severe fire period and a benign fire period, for instance) Recall my comment that fabricating fuel models involves a great deal of art. What constitutes a proper rating of any situation is very, very subjective. We spent hundreds of hours with users adjusting fuel model parameters to cause the NFDRS ratings to match subjective, nonquantitative appraisals of case situations.

SYSTEM VALIDATION

Currently, there is no common measurement of any fire phenomenon to correlate with NFDRS ratings.

Don Haines and his coworkers at East Lansing will soon publish the results of an evaluation using (1) probability of a fire day, (2) probability of a large fire day (a day with one or more fires 10 acres and larger), (3) number of fires per day and (4) number of fires per fire day (Haines and others, in preparation). The results are encouraging and show that the Ignition Component and the Spread Component are highly correlated with those four measures of fire acitivity.

Most of the published work has been directed at validating components of the System such as the fuel moisture models (Simard and Main 1982; Simard and others, in preparation; Forsberg and other 1981; Harrington 1982; Loomis and Main 1980; Loomis and Blank 1981; Ottmar 1980). Much work has been done to evaluate the Rothermel spread model which is the basis of the NFDRS Spread Component (Andrews 1980; Bevins 1976; Brown 1972; Sneeuwjagt 1974; Sneeuwjagt and Frandsen 1977).

An effort is under way at the Northern Forest Fire Laboratory to develop software to access the Fire Report Library (Yancik and Roussopoulos 1981) and Fire Weather Library (Furman and Brink 1975) for comparisons similar to those done at East Lansing. The problem remains, however, that without an agreed-upon set of measures of fire phenomena and standard methods of analysis, it is impossible to determine how good the System is or how much proposed changes to the NFDRS would improve its performance.

SUMMARY

A technical revision of the NFDRS alone will not cure all the problems with the fire-danger rating programs. What is needed is a national program that will emphasize research in NFDRS application, management, and validation, and that will revise the System as required.

Piecemeal or regional revisions would be unwise because every modification requires an extensive checkout of the impact on System performance. It would be much more efficient if all the contemplated changes were made at once by one group. A research, development, and applications program would be appropriate for this task.

Training at the national, regional, and local levels is a continuing need and must be provided for. Fire management is constantly evolving. It takes knowlegeable, experienced people to redefine the role of NFDRS and to properly apply the System.

Fire management is a demanding and increasingly complex job. The need to especially good decisionmaking is increased by the high cost of wildfire suppression and the forces that must be available to do the job. If properly supported and implemented, the NFDRS can contribute to efficient fire management.

☆U S GOVERNMENT PRINTING OFFICE 1984-0-776-032/10,501

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The National Fire-Danger Rating System (NFDRS), implemented in 1972, has been revised and reissued as the 1978 NFDRS. This report describes the full developmental history of the NFDRS, including purpose, technical foundation, and structure. Includes an extensive bibliography and appendixes.

KEYWORDS: fire, fire danger rating, forest fire hazard, forest fire behavior, forest fire risk, technical documentation

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**Intermountain
Forest and Range
Experiment Station
Ogden, Utah 84401**

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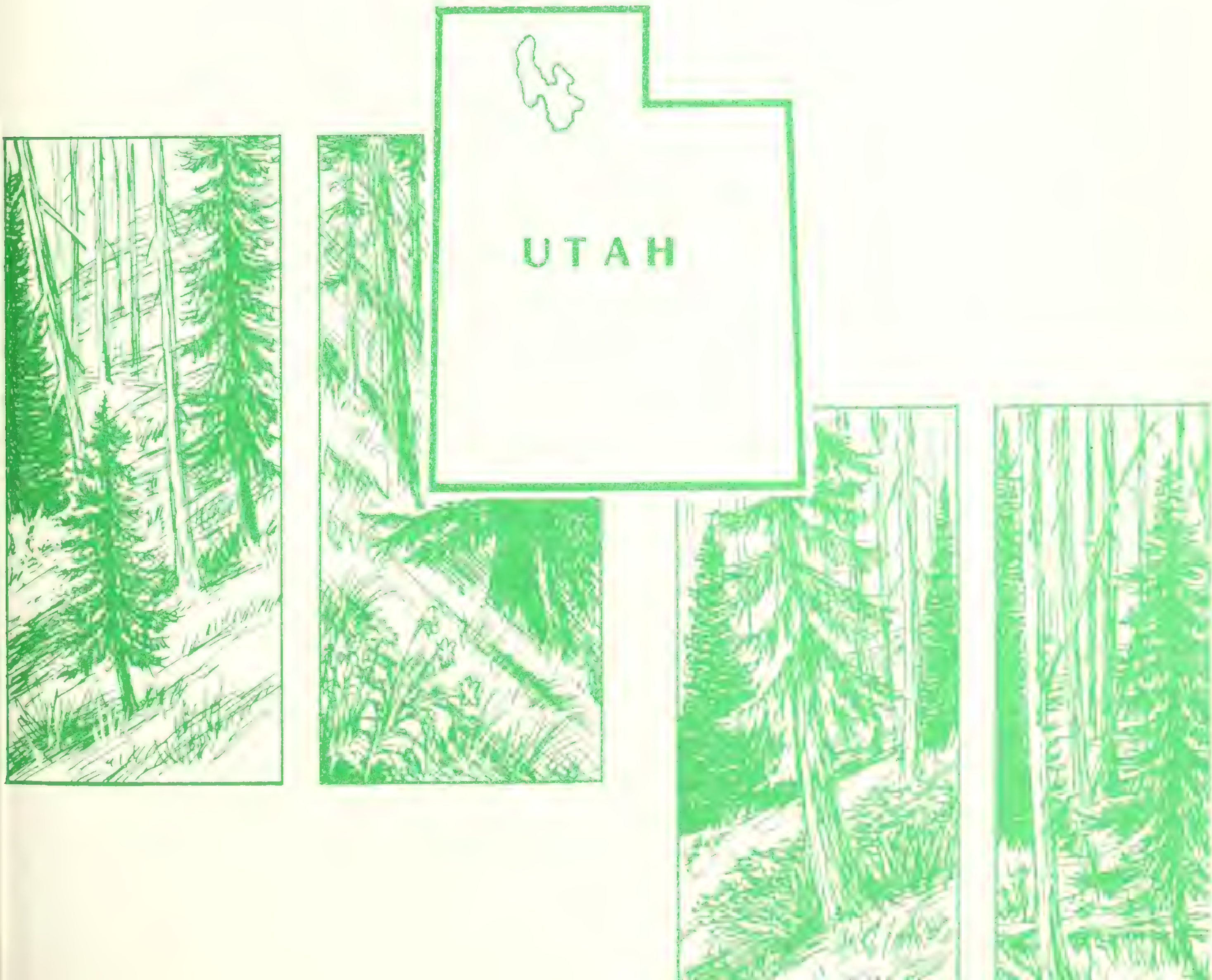
July 1984

Coniferous Forest Habitat Types of Northern Utah

**Ronald L. Mauk
Jan A. Henderson**



THE AUTHORS

The field work, analysis, and the preparation of the initial manuscript for this publication occurred while Ron Mauk was a graduate student in the Department of Forestry and Outdoor Recreation at Utah State University. He is currently employed by Hughes Aircraft Co. in Tucson, Ariz. Dr. Jan Henderson was an assistant professor in the Department of Forestry and Outdoor Recreation at Utah State University. He is currently a forest ecologist with the Olympic National Forest, Olympia, Wash.

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Many public foresters as well as colleagues at Utah State University provided advice during the course of this study. Dr. Robert D. Pfister (formerly Intermountain Station; currently University of Montana) generously provided major technical assistance and data from stands in the subalpine forests in northern Utah. Robert Steele (Intermountain Station) provided data from stands in southeastern Idaho, as well as helpful suggestions regarding classification units. Reconnaissance data from the Uintah and Ouray Indian Reservation were provided by Warren L. White (Utah Division of Forestry and Fire Control). Arthur Holmgren and Leila Shultz (Intermountain Herbarium, Utah State University) freely helped with many taxonomic problems.

Donald L. Anderson (Bureau of Land Management) authored parts of the preliminary northwestern Utah classification and was responsible for much of the plant identification. In addition, many other Utah State University undergraduate forestry students served as valuable field or office assistants.

RESEARCH SUMMARY

A habitat type classification is presented for the coniferous forests of northern Utah and adjacent areas of Idaho and Wyoming. The classification and descriptions are based on data from about 1,100 sample stands covering 6 years of reconnaissance sampling. The habitat type concept, a hierarchical system of land classification, is based on potential natural vegetation of forest sites. A total of 8 climax series, 36 habitat types, and 24 phases of habitat types were identified. A diagnostic key is provided for field identification of the habitat types based on the indicator species used in the development of the classification.

In addition to a site classification, mature coniferous forest communities are described and tables provided to portray ecological distributions of all species. Potential productivity for timber, physical site characteristics, climatic characteristics, and surface soil characteristics are also described for each type. Preliminary implications affecting natural resource management and general successional dynamics for both tree and undergrowth species are discussed.

CONTENTS

Figures:

Coniferous Forest Habitat Types of Northern Utah

Ronald L. Mauk
Jan. A. Henderson

INTRODUCTION

Forest vegetation, and the sites that support it, are complex entities in themselves. Vegetation also reflects, however, the environmental regime under which it has developed to the present, and will develop in the immediate future. Thus, some system of resource classification is fundamental to sound, intelligent management of both the forest vegetation and other site resources.

Pfister and others (1977) have briefly reviewed some of the classification systems that have been employed. They state that forest managers and researchers usually find special classifications inadequate for general use. For example, a cover-type classification often encompasses great variability in forest conditions and, in addition, provides little information on successional trends or past disturbance. A "physical-site" classification, on the other hand, has little relationship to forest vegetation, even though the site environment substantially influences vegetation. The need for an integrated classification system is clear. And as these authors have further noted, such a system must also provide a base for improving communications, management interpretations, and research applications.

The habitat type approach to forest site classification is such a system. Developed by Rexford Daubenmire (1952) for forests of northern Idaho and adjacent Washington, with subsequent modification (Daubenmire and Daubenmire 1968), it has proven to be useful for management and research applications (Layser 1974; Pfister 1976). Thus, in 1971, the habitat type classification system was selected for development and application in Montana (Pfister and others 1977). As part of a program to extend such classifications throughout western North America, the classification of Utah forest sites was begun in 1975 as a cooperative research effort between the Department of Forestry and Outdoor Recreation of Utah State University, and the Intermountain Forest and Range Experiment Station and the Intermountain Region of the Forest Service, U.S. Department of Agriculture. This report constitutes the subsequent classification of the conifer-dominated lands of northern Utah. It is based on a combination and secondary analysis of data from (1) northwestern Utah preliminary classification (Henderson and others 1976), (2) Uinta Mountains preliminary classification (Henderson and others 1977), and (3) Utah subalpine forest classification (Pfister 1972).

OBJECTIVES AND SCOPE

As a part of a broad regional classification program, the objectives of the northern Utah study correspond to those outlined by Pfister and others (1977):

1. Development of a classification for conifer-dominated forest lands based on potential vegetation.
2. Description of the general geographic, physiographic, climatic, and edaphic features of each type.
3. Description of the mature forest communities (late seral) as well as the potential climax communities (associations) characteristic of each type.
4. Presentation of information on successional development, timber productivity potential, and other biological observations of importance to forest land managers.

To provide a continuity between the classifications of specific areas, our terminology corresponds largely to that of Steele and others (1981). Reference to the glossary included in that publication as appendix G (p. 137-138) is encouraged. Also, their format of organization and presentation has been followed.

The area of study includes the forested lands of northern Utah and adjacent Idaho (fig. 1). As such, the classification encompasses parts of five National Forests, as well as proximate public and private lands. Some lands supporting certain plant communities were not included. Expressly excluded were riparian sites dominated by *Populus angustifolia, Betula occidentalis, Acer negundo*, or *Salix*; various woodlands such as *Acer grandidentatum, Quercus gambelii, Juniperus osteosperma, J. scopulorum, Pinus edulis*, or *P. monophylla*; and *Populus tremuloides* lands of uncertain successional status. This classification therefore includes the forested lands that are potentially capable of supporting at least a 25 percent canopy cover of conifers, excluding woodland species.

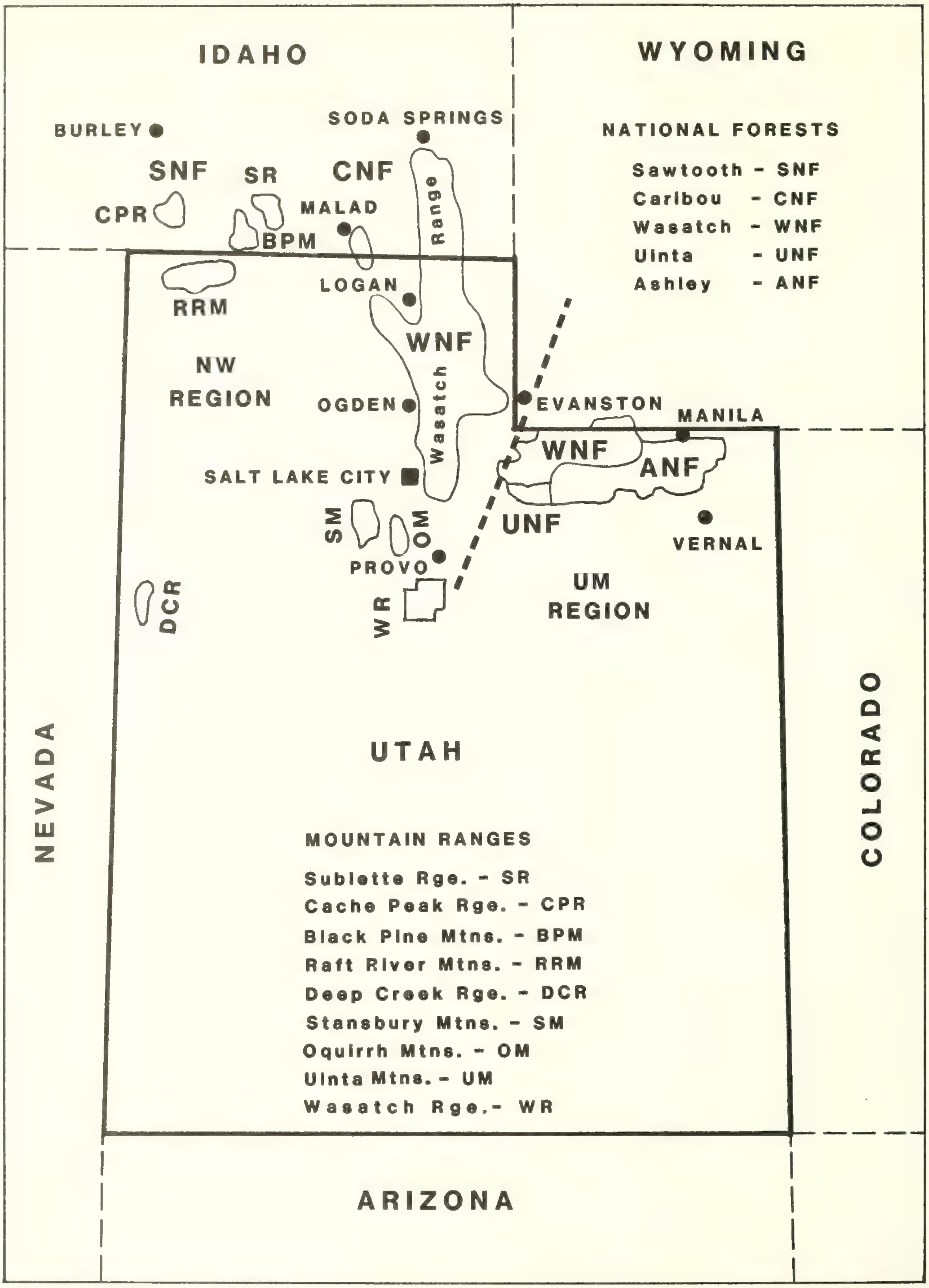

Figure 1.—Distribution of sampled National Forests and mountain ranges in the northern Utah study area. Heavy dashed line delineates northwestern and northeastern (Uinta Mountain) regions, as referenced in the habitat type discussions.

METHODS

Plot Sampling

Mature to near-climax stands were sampled with temporary plots in an attempt to represent the full range of environmental conditions and late successional stages for forested sites throughout northern Utah and adjacent Idaho. Sampling was conducted over three summers. The methodology of the study essentially followed that of Pfister and others (1977), as recently discussed in further detail by Pfister and Arno (1980).

Stands were selected for sampling by first inspecting forest conditions along a traveled transect (usually a road or trail), generally following an elevational gradient. The identification of potential stands was based on the overstory, undergrowth, substrate, and environmental characteristics, and also the relationships to both adjacent stands and the study area as a whole. Plots were then objectively located in the most representative and homogeneous parts of the most mature stands of the area. Ecotones, exceptionally dense clumps, openings, rock outcrops, and seeps were purposefully avoided. Recently disturbed sites were also avoided, but this was not always possible because of the intensive use that has occurred throughout much of the study area.

The use of random or systematic systems for stand selection was rejected. Such methods are inefficient, generating many stands that either are not mature, which is necessary for classifying habitat types, or that represent ecotone conditions. Random selection systems also tend to oversample abundant communities and undersample scarcer ones.

Three distinct types of plots were used for sampling: "survey," "reconnaissance," and "detailed research" or "Daubenmire" (after Henderson and West 1977). All data were recorded on specially designed cards. In addition, extensive photography was employed, which proved to be valuable during data analysis. Survey plots were circular. During 1975, a 375-m^2 plot (about one-tenth acre) was used, with a centered 50-m^2 subplot for tree regeneration. After 1975, a 500-m^2 plot (about one-eighth acre) and 100-m^2 subplot were adopted in order to provide a better representation of overstory conditions. In exceptionally dense stands of *Pinus contorta*, however, a 250-m^2 plot (50-m^2 subplot) was substituted to reduce data collection time.

The less intensive reconnaissance plot was chiefly used in 1977 for verifying the classification and for supplemental sampling. Reconnaissance plots were similar to the survey plots, except that plot boundaries (encompassing about the same area) were estimated, not measured, and less data were collected. One investigator can lay out and collect the data on a reconnaissance plot in about 20 minutes, versus 45 minutes to 2 hours for the survey plot, or 2 to 4 hours for the detailed research plot (Henderson 1979).

The detailed research plot was employed to provide both training and recurrent calibration of cover estimates. This plot was derived from Daubenmire (1959; see also Daubenmire and Daubenmire 1968). The cover of each undergrowth species was estimated independently, using 50 to 100 systematically placed 0.1-m^2 quadrats, recorded by six cover classes. Cover of a species was calculated as the mean of the cover class midpoints for all quadrats. Plot configuration and area matched that of the survey plots—circular, with quadrats placed along four radii. The accuracy and efficiency of this plot with respect to the other types of plots has been discussed by Henderson (1979).

For all types of plots, undergrowth data consisted of the canopy coverage of each vascular plant species ocularly estimated to the nearest percentage, from 1 to 10 percent, and to the nearest 5 percent thereafter. When present with less than 0.5 percent cover, a species was recorded as a trace and assigned a value of 0.3 for computational purposes. In addition, a species that was absent in a plot but represented in the immediate stand was noted as a "+" and ignored in computations unless the stand was exceptionally depauperate.

Unknown species were collected for subsequent identification. Mosses were treated collectively. Cover of minor species was not recorded for reconnaissance plots.

Overstory data included the canopy coverage of each tree species, estimated by three breast-height-diameter classes (using the procedure for undergrowth): less than 4 inches; 4 to 12 inches; and greater than 12 inches (less than 10 cm; 10 to 30 cm; and greater than 30 cm). For survey and detailed survey plots, a stand table was recorded by 4-inch (10-cm) diameter classes for basal area determination; and established seedlings 0.5 to 4.5 feet in height (15 to 137 cm) were counted on the regeneration subplot. On each reconnaissance plot, basal area for each species was estimated with a 10-factor prism; established seedlings were noted but not counted. These data were used extensively in assessing successional trends.

Whenever possible, the age and height of at least one relatively free-growing individual for each species were determined to provide an estimate of timber productivity. Only one tree was usually measured for each reconnaissance plot.

Physical site characteristics were determined for each plot. These included elevation, aspect (azimuth), slope (percentage), and a qualitative position and configuration. Survey and detailed research plots were referenced to conspicuous landmarks for possible revisitation during the study, and all plots were located on USGS topographic quadrangles when these were available.

Soil characteristics were determined largely on site. These included parent material composition, texture of the upper 10 inches (25 cm) of surface soil, litter depth (in cm); charcoal presence, and the relative presence of coarse fragments (collectively referred to as "gravel" throughout the descriptions). In addition, the percentage of area in bare soil and exposed rock (material greater than 3 inches in diameter) was estimated for survey and detailed research plots, using the coverage procedure for vegetation. A sample of the upper 20 cm of soil was collected. Bedrock and surficial geology were determined whenever possible from geological maps on other published studies (Atwood 1909; Bradley 1964; Kinney 1955; Stokes 1962; Stokes and Madsen 1961; Williams 1946).

Notes were made on stand and fire history and the relationship of the sampled stand to adjacent stands as well as on wildlife and domestic livestock use, forest diseases and pests, and general management implications.

During the summer of 1975, a total of 445 plots were sampled in the Wasatch, Caribou, and Sawtooth National Forests of northwestern Utah and adjacent Idaho (fig. 1). This was done by three two-person teams. In 1975, 256 plots were sampled in the Uinta Mountains, Utah, and Wyoming by two two-person teams. This work covered the Ashley and Wasatch National Forests and an adjacent section of the Uinta National Forest. During the summer of 1977, 292 reconnaissance plots were sampled throughout northern Utah by three individuals for classification verification or for supplemental sampling where data were scant. In addition, about 10 survey plots in 1979, 25 plots in 1980, and 11 plots in 1981 were taken for the latter purpose.

In 1975 and 1977, the higher forested mountain ranges of the Great Basin area were visited. These included the Deep Creek Range and Oquirrh, Raft River, and Stansbury Mountains of Utah; and the Black Pine Mountains, Sublette Range, and Cache Peak Range (including the Albion Mountains) of Idaho. Sampling was generally more intensive in the more northern mountain ranges where accessibility was better. All of these areas, except the Deep Creek Range, are represented in the data by 47 plots.

In addition, 84 plots sampled by Pfister (1972) in northern Utah were used for verification and then incorporated into the data base. Thus, the classification has been developed from about 1,120 plots. The distribution of sample stands is presented by National Forest and State or geographic region in appendix A.

Office Procedures

The development of this habitat type classification follows in general the data analysis procedures discussed in detail by Pfister and Arno (1980). The classification was developed through a series of successive approximations and revisions. Its general chronological development is outlined as follows:

1. Subjective first groupings were made following each field season (1975 and 1976). These were based on habitat types reported from adjacent studies (see below) and from observations made during sampling. Possible new habitat types were briefly described.
2. Following the identification of voucher collections, all data were prepared for computer processing. Computer programs were developed by the senior author for specific analysis throughout the course of the study.
3. Synthesis tables (Mueller-Dombois and Ellenberg 1974) were computer generated for the stands of each series, that is, all stands having the same projected climax tree species. Such tables allow visual comparisons of data between stands. The initial stand arrangement was based on the first groupings. These tables were studied in detail to identify general similarities of vegetal composition. Species showing consistent differential distributions were noted. A series of new tables were then created by rearranging similar stands. From these, possible indicator species were identified. The final stand arrangement provided the formal basis for the series, habitat types, and phases.
4. Characteristic vegetational parameters for the habitat types and phases were identified and briefly described. From these, a key to the habitat types was constructed. When the key was then applied to all stands, several problems were identified, which resulted in slight revisions of the classifications.
5. Summary tables were computer generated for constancy and average cover of important species for each habitat type and phase (appendix C).
6. Computer-generated summaries of geographic locations, physical site parameters, soils, etc., were inspected to insure that specific environmental patterns could be related to each habitat type and phase. This process also identified a few new situations, which were mainly phases. These summaries provided the basis for appendix D.
7. Terminology for the types was correlated wherever possible to that of previous studies (Daubenmire and Daubenmire 1968; Pfister 1972; Wirsing and Alexander 1975; Hoffman and Alexander 1976; Pfister and others 1977; Steele and others 1979, 1981) and to express the interrelationships as clearly as possible.
8. The preliminary classifications (1976, 1977) which included descriptions of the types were distributed, presented at training sessions, and put into use. Evaluations by the users were solicited. Reported problems sometimes revealed geographic areas or portions of the classifications that required additional sampling.
9. The preliminary classifications including data from subsequent sampling were combined in this report. This process identified several significant problem areas in the preliminary classifications. Thus, the entire analysis process was repeated to yield the final classification. Specific classification changes have been noted in the habitat type descriptions. Several of these were based on the treatment of eastern Idaho and western Wyoming by Steele and others (1983). Yet other changes reflected significant departures from both that treatment and the preliminary classifications of northern Utah. Finally, approximately 3 percent of the sample stands (excluding *Populus tremuloides* communities) did not fit the final classification. Most of these were evidently ecotones, early-seral stands, or unusual forest communities; some stands were woodland communities; and a few stands may represent habitat types that are poorly represented in this area.
10. For the final classification more phases were identified, particularly for situations that correspond to descriptions from adjacent studies as well as from ongoing work in southern Utah. A phase may represent a broad transition (usually occupying significant landscape) between two adjacent types—for example, ABLA/BERE h.t., RIMO phase. (Because of frequent reference to habitat type names, abbreviations are used for convenience throughout this report; these are shown in table 1.) A phase may also represent a difference of species dominance in a third layer (the habitat type is defined by dominants or indicator species in two layers), such as the PIPO/FEID h.t., ARPA and ARTR phases.

ıble 1.—Northern Utah forest habitat types

ɔbreviation	Habitat types and phases: Scientific names	Common names
	***Pinus flexilis* Climax Series**	
FL/CELE h.t.	*Pinus flexilis/Cercocarpus ledifolius* h.t.	limber pine/curlleaf mountain-mahogany
FL/BERE h.t.	*Pinus flexilis/Berberis repens* h.t.	limber pine/Oregongrape
	***Pinus ponderosa* Climax Series**	
PO/CAGE h.t.	*Pinus ponderosa/Carex geyeri* h.t.	ponderosa pine/elk sedge
PO/FEID h.t.	*Pinus ponderosa/Festuca idahoensis* h.t.	ponderosa pine/Idaho fescue
-ARPA phase	-*Arctostaphylos patula* phase	-greenleaf manzanita phase
-ARTR phase	-*Artemisia tridentata* phase	-big sagebrush phase
-FEID phase	-*Festuca idahoensis* phase	-Idaho fescue phase
	***Pseudotsuga menziesii* Climax Series**	
ͻME/PHMA h.t.	*Pseudotsuga menziesii/Physocarpus malvaceus* h.t.	Douglas-fir/ninebark
-PAMY phase	-*Pachistima myrsinites* phase	-myrtle pachistima phase
ͻME/ACGL h.t.	*Pseudotsuga menziesii/Acer glabrum* h.t.	Douglas-fir/mountain maple
ͻME/OSCH h.t.	*Pseudotsuga menziesii/Osmorhiza chilensis* h.t.	Douglas-fir/mountain sweetroot
-PAMY phase	-*Pachistima myrsinites* phase	-myrtle pachistima phase
ͻME/CARU h.t.	*Pseudotsuga menziesii/Calamagrostis rubescens* h.t.	Douglas-fir/pinegrass
ͻME/CELE h.t.	*Pseudotsuga menziesii/Cercocarpus ledifolius* h.t.	Douglas-fir/curlleaf mountain-mahogany
ͻME/BERE h.t.	*Pseudotsuga menziesii/Berberis repens* h.t.	Douglas-fir/Oregongrape
-CAGE phase	-*Carex geyeri* phase	-elk sedge phase
-JUCO phase	-*Juniperus communis* phase	-common juniper phase
-SYOR phase	-*Symphoricarpos oreophilus* phase	-mountain snowberry phase
-BERE phase	-*Berberis repens* phase	-Oregongrape phase
ͻME/SYOR h.t.	*Pseudotsuga menziesii/Symphoricarpos oreophilus* h.t.	Douglas-fir/mountain snowberry
	***Picea pungens* Climax Series**	
PU/AGSP h.t.	*Picea pungens/Agropyron spicatum* h.t.	blue spruce/bluebunch wheatgrass
PU/BERE h.t.	*Picea pungens/Berberis repens* h.t.	blue spruce/Oregongrape
	***Abies concolor* Climax Series**	
3CO/PHMA h.t.	*Abies concolor/Physocarpus malvaceus* h.t.	white fir/ninebark
3CO/OSCH h.t.	*Abies concolor/Osmorhiza chilensis* h.t.	white fir/mountain sweetroot
3CO/BERE h.t.	*Abies concolor/Berberis repens* h.t.	white fir/Oregongrape
-SYOR phase	-*Symphoricarpos oreophilus* phase	-mountain snowberry phase
-BERE phase	-*Berberis repens* phase	-Oregongrape phase
	***Picea engelmannii* Climax Series**	
EN/EQAR h.t.	*Picea engelmannii/Equisetum arvense* h.t.	Engelmann spruce/common horsetail
EN/CALE h.t.	*Picea engelmannii/Caltha leptosepala*	Engelmann spruce/elkslip marshmarigold
EN/VACA h.t.	*Picea engelmannii/Vaccinium caespitosum* h.t.	Engelmann spruce/dwarf blueberry
EN/VASC h.t.	*Picea engelmannii/Vaccinium scoparium* h.t.	Engelmann spruce/grouse whortleberry

(con.)

n other cases, a phase may distinguish geographic subivisions of types that have wide distributions—for xample, PSME/ACGL h.t., PAMY phase.

11. Additional analytic methods were employed during ıe final classification revision. Several index-ofimilarity matrices were computer generated for paricularly difficult groups of stands. Initially, "Sorenson's ' index" (Dick-Peddie and Moir 1970) and, later, the "Bray-Curtis index" (Mueller-Dombois and Ellenberg 1974) were used, with the species' percentage of cover as attributes. Cluster analysis dendrograms were also created from the similarity matrices through the use of the general purpose program, CLUSTAR (Marshall and Romesburg 1977), along with UPGMA clustering linkage (Unweighted Pair Group Method). Both of these analyses provided general insight for the problem areas.

Table 1.—(con.)

Abbreviation	Habitat types and phases — Scientific names	Common names
	***Abies lasiocarpa* Climax Series**	
ABLA/CACA h.t.	*Abies lasiocarpa/Calamagrostis canadensis* h.t.	subalpine fir/bluejoint reedgrass
ABLA/STAM h.t.	*Abies lasiocarpa/Streptopus amplexifolius* h.t.	subalpine fir/claspleaf twisted-stalk
ABLA/ACRU h.t.	*Abies lasiocarpa/Actaea rubra* h.t.	subalpine fir/baneberry
ABLA/PHMA h.t.	*Abies lasiocarpa/Physocarpus malvaceus* h.t.	subalpine fir/ninebark
ABLA/ACGL h.t.	*Abies lasiocarpa/Acer glabrum* h.t.	subalpine fir/mountain maple
ABLA/VACA h.t.	*Abies lasiocarpa/Vaccinium caespitosum* h.t.	subalpine fir/dwarf blueberry
ABLA/VAGL h.t.	*Abies lasiocarpa/Vaccinium globulare* h.t.	subalpine fir/blue huckleberry
ABLA/VASC h.t.	*Abies lasiocarpa/Vaccinium scoparium* h.t.	subalpine fir/grouse whortleberry
-ARLA phase	-*Arnica latifolia* phase	-broadleaf arnica phase
-CAGE phase	-*Carex geyeri* phase	-elk sedge phase
-VASC phase	-*Vaccinium scoparium* phase	-grouse whortleberry phase
ABLA/CARU h.t.	*Abies lasiocarpa/Calamagrostis rubescens* h.t.	subalpine fir/pinegrass
ABLA/PERA h.t.	*Abies lasiocarpa/Pedicularis racemosa* h.t.	subalpine fir/sickletop pedicularis
-PSME phase	-*Pseudotsuga menziesii* phase	-Douglas-fir phase
-PERA phase	-*Pedicularis racemosa* phase	-sickletop pedicularis phase
ABLA/BERE h.t.	*Abies lasiocarpa/Berberis repens* h.t.	subalpine fir/Oregongrape
-PIFL phase	-*Pinus flexilis* phase	-limber pine phase
-RIMO phase	-*Ribes montigenum* phase	-mountain gooseberry phase
-CAGE phase	-*Carex geyeri* phase	-elk sedge phase
-JUCO phase	-*Juniperus communis* phase	-common juniper phase
-PSME phase	-*Pseudotsuga menziesii* phase	-Douglas-fir phase
-BERE phase	-*Berberis repens* phase	-Oregongrape phase
ABLA/RIMO h.t.	*Abies lasiocarpa/Ribes montigenum* h.t.	subalpine fir/mountain gooseberry
-THFE phase	-*Thalictrum fendleri* phase	-Fendler meadowrue phase
-PICO phase	-*Pinus contorta* phase	-lodgepole pine phase
-TRSP phase	-*Trisetum spicatum* phase	-spike trisetum phase
-RIMO phase	-*Ribes montigenum* phase	-mountain gooseberry phase
ABLA/OSCH h.t.	*Abies lasiocarpa/Osmorhiza chilensis* h.t.	subalpine fir/mountain sweetroot
ABLA/JUCO h.t.	*Abies lasiocarpa/Juniperus communis* h.t.	subalpine fir/common juniper
	***Pinus contorta* Climax Series**	
PICO/CACA c.t.[1]	*Pinus contorta/Calamagrostis canadensis* c.t.	lodgepole pine/bluejoint reedgrass
PICO/VACA c.t.	*Pinus contorta/Vaccinium caespitosum* c.t.	lodgepole pine/dwarf blueberry
PICO/VASC c.t.	*Pinus contorta/Vaccinium scoparium* c.t.	lodgepole pine/grouse whortleberry
PICO/JUCO c.t.	*Pinus contorta/Juniperus communis* c.t.	lodgepole pine/common juniper
PICO/ARUV h.t.	*Pinus contorta/Arctostaphylos uva-ursi* h.t.	lodgepole pine/bearberry
PICO/BERE c.t.	*Pinus contorta/Berberis repens* c.t.	lodgepole pine/Oregongrape
PICO/CARO h.t.	*Pinus contorta/Carex rossii* h.t.	lodgepole pine/Ross sedge

Total number of habitat types = 36

Total number of habitat type, phase, and *Pinus contorta* community type categories = 67

[1]Community type.

Because percentage of cover was used as the importance value for these indices, "common" species having high cover values throughout portions of a series often tended to confound relationships evident in the synthesis tables and field observations. Thus the indices consistently yielded community type or cover type groupings rather than habitat type groupings. Consequently, various transformations were applied to the data of which a square-root transformation of cover consistently yielded groups most closely related to the groups formed by the synthesis table approach. Pfister and Arno (1980) overcame this problem by using cover class codes instead of percentage of cover.

12. A generalized description was prepared for each defined habitat type, based on the final summary table This included geographic distribution, physical environment features, key features of vegetation, descriptions phases and the basis for their separation, relationships to frequently adjacent types, general implications for management, and relationships to other types reported in the literature.

13. This classification provides the foundation for developing "site-specific" considerations useful for management or for future research. For example, consider the appraisal of timber productivity, which immediately follows. An understanding of the environmental and vegetative features of each habitat type can help the user answer many pressing management questions. Some of the more obvious relationships have been stressed in the descriptions. Undoubtedly more will become known as the system is used.

Timber Productivity

Timber productivity was one of the key management considerations for which data were collected in the northern Utah study. Our methods of analysis followed those of Pfister and others (1977).

For each plot, one dominant or codominant tree of each species was selected for age and height measurement, wherever possible. Trees were rejected for further analysis if increment cores exhibited diameter-growth suppression during any 10-year period. The trees used, then, represent the productivity of relatively free-growing trees from natural stands.

Pfister and others (1977) outlined the special procedures and considerations for determining site index from age-height data. For curves based on total age, the number of years to reach breast height must be determined. Species for which site index curves are not available require the use of a substitute curve. In addition, each curve has a range of basic age-height data from which it was derived. Trees having values not included within these ranges were rejected for site index analysis. Criteria used to determine total age and the sources of site index and yield capability curves are summarized in table 2.

Lynch's (1958) *Pinus ponderosa* curve was used to determine *Pseudotsuga* site index rather than Brickell's (1968) curve because the latter does not have yield capability relationship.

Although we had to determine total age (introducing a possible error), the *Pinus ponderosa* curve was used to determine *Abies concolor* and *Pinus flexilis* site index. This use also facilitated a more direct comparison with *Pseudotsuga*, which is the most common associate of these species. Alexander's (1967) *Picea engelmannii* curve also appeared to reflect rather reasonably *Abies concolor* site index, but it poorly represented *Pinus flexilis*.

Alexander's (1967) curve for *Picea engelmannii* was used for this species instead of Brickell's (1966) curve because a yield capability relationship was available and total age determination was not necessary. This curve was also used for *Abies lasiocarpa* and *Picea pungens* site index.

Alexander's curve (1966) was used for *Pinus contorta*; however, individual values were not corrected for effects from excessive crown competition. Thus, some site index and yield capability values may be arbitrarily low.

Table 2.—Criteria and sources for determining site index and estimating yield capability

Species	Estimated years to obtain breast height	Source of site curve[1]	Yield capability (all trees · fig. 2)
PIPO	15	Lynch 1958	Brickell 1970
PSME	15	used PIPO curves	
ABCO	15	used PIPO curves	
PIFL	20	used PIPO curves	
PICO	10	Alexander 1966	Pfister and others 1977[2]
PIEN	([3])	Alexander 1967	Pfister and others 1977[4]
PIPU	([3])	used PIEN curves	
ABLA	([3])	used PIEN curves	

[1]A FORTRAN computer program was written for site-index determination and yield capability estimation. Site-index algorithms of Brickell (1970) were used for the PIPO and PICO curves, and that of Clendenen (1977) for the PIEN curve. Algorithms are based on the sources shown and additionally convert 100-year base age curves to 50-year base age.

[2]A *Larix occidentalis* curve for all trees (0.5 inch) was used for PICO. This curve was developed from data in Schmidt and others (1976) by Pfister and others (1977), who explain, "Brickell's (1970) curves for PICO and LAOC (trees larger than 5.0 inches) were nearly identical . . . . The LAOC curve for all trees appears to be as accurate as any available for estimating PICO yield capability for all trees."

[3]Curve based on breast-height age was used.

[4]The curve used was derived by R. D. Pfister from yield data of Alexander and others (1975). It is described in Pfister and others (1977, p. 128-129).

The site index data (base age 50 years) have been summarized by species within habitat type (appendixes E-1 and E-2). Because of regional differences in habitat type occurrence and apparent regional differences in productivity for some habitat types, all timber productivity data were summarized separately for the northwestern region and the Uinta Mountains. The mean site index was calculated whenever three or more values were available; with five or more values, a 95-percent confidence interval for estimating the true population mean was calculated. The same procedure was used for summarizing basal areas of sample stands.

Site index alone can be used to compare differences in site productivity. A more useful assessment, however, is that of net estimated yield capability (cubic-foot production). Pfister and others (1977) further explain yield capability:

> Until managed-stand yield tables are completed, the best approach is to use natural-stand yield tables for assessing yield capability. As stated by Brickell (1970), "Yield capability as used by Forest Survey, is defined as mean annual increment of growing stock attainable in fully stocked natural stands at the age of culmination of mean annual increment." (In other words, yield capablility = maximum mean annual increment attainable in fully stocked natural stands.)

The curves used to determine yield capability from site index are presented in figure 2; sources of the relationships are discussed in table 2. All yield capability values (cubic feet/acre/year) are based on all trees (0.5 inches d.b.h.).

A computer program was developed for the graphic and statistical analyses of the yield capability estimates. The procedures employed were essentially those of Pfister and others (1977):

1. Yield capability was estimated for each site tree according to the criteria presented in table 2. These estimates were plotted within each category (habitat type or phase, by region) for a visual display of data distribution.

2. Mean yield capability based on all site trees in each category was calculated. Cutoffs were established to approximate 90 percent of the range of our data. Values were combined and new means and cutoffs were determined for instances where regional data were scant.

3. For habitat types (or phases) where stockability appeared to limit productivity, a stockability factor was developed. Basal area data for plots in these categories were compared to Meyer's (1938) basal area data for fully stocked "normal" stands, following the approach of MacLean and Bolsinger (1973). From these calculations and additional observations, an average mean stockability factor was determined for several categories and yield capability based on each site tree was multiplied by the respective plot factor (the ratio of basal areas) to determine the adjusted yield capability. Cutoffs were established to approximate 90 percent of the range of data.

Our current best estimates of yield capability are presented by region in appendix E-3 and E-4 for cubic

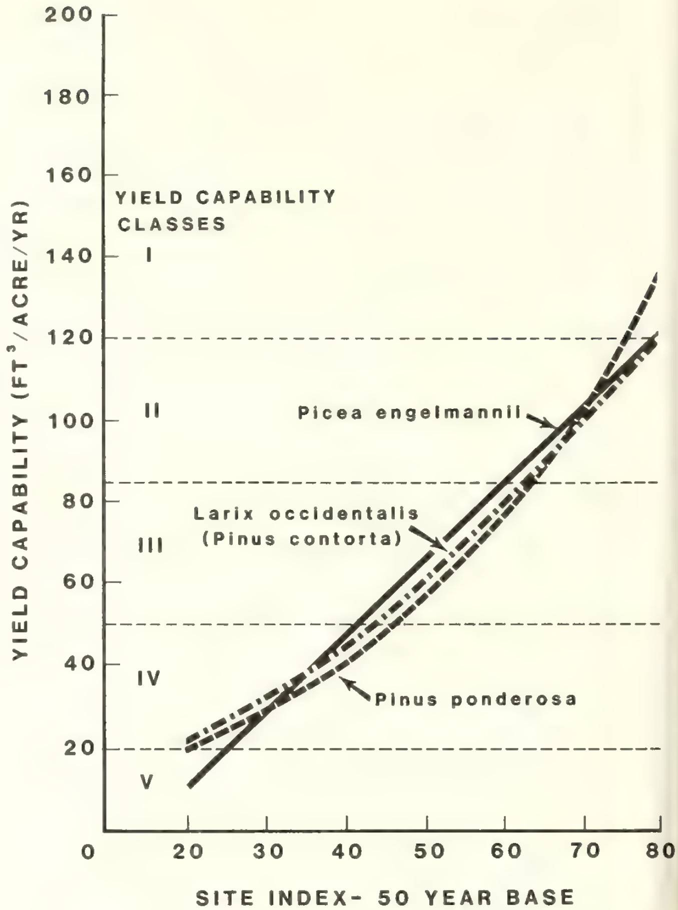

Figure 2.—Yield capability of fully stocked natural stands in relation to site index (adapted from Pfister and others 1977).

feet/acre/year. Forest Survey classes and terminology for cubic-foot production are employed in the habitat type descriptions under the productivity/management section. These are (in cubic feet/acre/year): less than 20, very low; 20-50, low; 50-85, moderate; 85-120, high; and greater than 120, very high.

As Daubenmire (1976) emphasized, natural vegetation serves as a convenient indicator of productivity over large areas of land. Productivity within habitat types (appendix E), however, often varies substantially. The following section explains this variation and tells how to reduce it:

1. Site index curves were used to obtain productivity estimates from yield tables. Different height-growth patterns undoubtedly occur on different sites just as they have been shown to vary with habitat type (Daubenmire 1961); data to account for this variation are not available, however.

2. Yield tables and site curves have not been developed for all species or growth regions. Extrapolation is therefore necessary and tenuous at times; for instance, when we use use Lynch's curve for several different montane species (table 2).

3. Yields of mixed stands can be estimated by several individual species yield tables, and a range in yield capability was common in individual stands. In addition,

intraspecies differences were present in individual stands. Productivity estimates often varied appreciably between individuals of *Abies lasiocarpa* and, to a lesser extent, *Picea engelmannii*. The trees were of about the same height but of a different age, yet all met the non-suppressed criterion. Typically, the older, more open-grown individual had an estimated value that was considerably less than an individual developing under conditions of partial shade (a developmental process which has been reviewed and modeled by Sperger [1980]). In most instances, only the older trees are represented in appendix E.

4. Some variation in productivity can be expected within a natural classification system, such as habitat types. The habitat type classification is based on abilities of species to reproduce and mature under competition, not on their rates of growth. The correlation between competitive strategies and productivity is imperfect at best. For example, in the ABLA/OSCH h.t., mature trees may draw on deeper soil moisture and achieve greater growth rates relative to the growth rates of immature trees, which may be limited by surface drought.

5. It has been suggested that productivity estimates could be improved by incorporating classifications of soils, topography, or climate. We have shown a major difference in productivity by separating the northwestern region and the Uinta Mountains data (appendix E). Differences in regional productivity have also been shown for Montana by Pfister and others (1977) through a separation of data from the east side and west side of the Continental Divide, as well as by Steele and others (1981, 1983) both through a regional treatment of Idaho and in relation to habitat types that are common to Montana. Differences in productivity within a habitat type due to topography, soils, or parent materials are also apparent in local areas. If more accurate estimates of species productivity are needed locally, sites could be stratified, for example, by parent materials such as quartzite vs. other materials for the Uinta Mountains. Because of the limitations of existing site index curves and yield tables, however, more precise estimates of productivity for large areas will not be possible until measuring techniques are improved.

6. Natural-stand yield capability by habitat type could be estimated more precisely by direct measurements of volume growth, rather than by using site index to enter a yield table based on averages. This would require analysis of existing timber inventory plots representing maximum growth potential or new field measurements.

7. Recent growth models (Stage 1973, 1975) utilize growth coefficients based on habitat types. These add a new dimension to yield prediction, provide the basis for developing managed-stand yield tables, and should improve our knowledge of productivity within and between habitat types.

Taxonomic Considerations

Unfortunately, a complete, up-to-date flora for the study area was not available during the field sampling; this caused a great deal of frustration. Many identifications, then, were based on floristic treatments of the surrounding areas (Davis 1952; Harrington 1954; Hitchcock and Cronquist 1973).

More than a thousand voucher collections of plants were made in the course of this study. Most were identified to species. Several specimens were identified or verified by Leila Shultz or Arthur Holmgren of the Intermountain Herbarium, Utah State University, Logan. About 200 of the better specimens have been deposited in this institution. Also, Mont E. Lewis (Forest Service, retired) identified several *Carex* specimens.

Sampling methodology required that field identification be made on material in vegetative, sterile, or less than optimal condition for taxonomic separation. This prevented the positive identification of some closely related species, primarily some graminoids, several of the composite complex, some penstemons, and many weedy species; in such cases, specimens were grouped under the most prevalent taxon for the region.

A few species presented special taxonomic problems. The descriptions provided in Hitchcock and others (1955-69) can be consulted for a precise separation of these and for general identification of the more common species mentioned in the descriptions.

The *Vaccinium globulare-V. membranaceum* complex is especially notable. The complex within the study area has been treated both as *V. globulare* and as *V. membranaceum* by various authors. The name *V. globulare* was adopted for type designation and description because all specimens collected in this study—from southeastern Idaho, extreme northern Utah, the western Uintas, and central Utah as well—correspond much closer to *V. globulare* material from Idaho than to *V. membranaceum* material from Washington and Oregon.

Vaccinium scoparium and *V. myrtillus* are difficult taxonomically, often intergrading in nearby States. Although Pfister (1972) listed *V. myrtillus* from the Uinta Mountains, all of our material corresponds to *V. scoparium*. Therefore, the *V. myrtillus* of Pfister's stands has been grouped under *V. scoparium*.

Separating *Osmorhiza chilensis* and *O. depauperata* is practically impossible without fruits. In *O. chilensis*, the fruit is rather strongly concavely narrowed at the summit, whereas in *O. depauperata* it is convexly narrowed (more rounded). Although *O. depauperata* is found mainly at mid-to-high elevations, both species often occur together on many sites within the study area. These species have been treated as ecologically similar in such situations.

Vegetatively, *Arnica latifolia* and *A. cordifolia* are quite similar; the cauline leaves of *A. latifolia*, however, tend to be largest toward the middle of the stem, being sessile or petiolate as well as rarely cordate; thus, its stems appear to be more leafy than those of *A. cordifolia*. The latter usually has its largest leaves at the base and longer petioles throughout. *A. latifolia* is usually restricted in occurrence to higher elevations and moist sites typically supporting *Picea engelmannii*. *A. cordifolia* is widespread and can occur on much drier sites.

SYNECOLOGICAL PERSPECTIVE AND TERMINOLOGY

The following two sections of discussion are quoted directly from Pfister and others (1977, p. 9-11).

Definition and Explanation of Habitat Type

All land areas potentially capable of producing similarplant communities at climax may be classified as the same habitat type (Daubenmire 1968). The climax plant community, because it is the end result of plant succession, reflects the most meaningful integration of the environmental factors affecting vegetation. Thus, each habitat type represents a relatively narrow segment of environmental variation and delineates a certain potential for vegetative development. One habitat type may support a variety of disturbance-induced, or seral, plant communities, but the vegetative succession will ultimately produce similar plant communities at climax throughout the type.

The climax community type, or association, provides a logical name for the habitat type—for example, *Pseudotsuga menziesii /Calamagrostis rubescens*. The first part of this name is based on the climax tree species, which is usually the most shade-tolerant tree adapted to the site. We call this level of classification the series and it encompasses all habitat types having the same dominant tree at climax. The second part of the habitat type name is based on the dominant or characteristic undergrowth species in the climax community type.

Use of climax community types to name habitat types does not imply that we have an abundance of climax vegetation in the present landscape. Actually, most vegetation in the landscape reflects some form of disturbance and various changes of succession towards climax. Nor do climax community type names imply that management is for climax vegetation; in fact, seral species are frequently preferred for timber and wildlife browse production. Furthermore, this method does not require the presence of a climax stand to identify the habitat type. It can be identified during most intermediate stages of succession by comparing the relative reproductive success of the tree species present with known successional trends and by observing the existing undergrowth vegetation. Successional trends toward climax usually appear to progress more rapidly in the undergrowth than in the tree layer. In very early stages of secondary succession, the habitat type can be identified by comparing the site with similar adjacent ones having mature stands.

Not all units of land will fit neatly into the habitat type system. As in most biological classifications, intergrades, or transitional areas will be encountered.

However, these situations occupy a small percentage of land and need not greatly detract from the utility of a habitat type classification.

The main advantage of habitat types in forest management is that they provide a permanent and ecologically based system of land stratification. Each habitat type encompasses a certain amount of environmental variation, but the variation within a habitat type should be less than that between types. In addition, habitat types provide a classification of climax plant communities. Plant succession should be generally predictable for each habitat type, and similar responses to management treatments can be expected on units of land within the same type.

Although transitional areas or ecotones between habitat types can be interpreted as being broad or narrow, our approach was to interpret them as narrowly as possible. In this way, more of the land surface is definable to habitat type and less is in ecotonal categories that may be impractical for use in resource management.

In discussing the relationship of a habitat type to certain environmental features, we have followed the polyclimax concept of Tansley (1935). Thus, a **climatic climax** develops on deep loamy soils of gently undulating relief; an **edaphic climax** differs from the climatic climax due to extreme soil condition such as coarse texture or poor drainage; and a **topographic climax** reflects compensating effects of topography on microclime. The **topoedaphic climax** is a convenient way to designate deviation from a climatic climax due to combined effects of edaphic and topographic features. Some habitat types reflect only one type of climax, but the majority of them occur in two or more of the above categories in response to interaction of environmental factors.

Habitat Types Versus Continuum Philosophy

A vigorous debate has been carried on for many years by ecologists who study plant communities—i.e., phytosociologists. Although several philosophies have been developed to interpret plant-community organization, two of them are often the center of debate: (1) the advocates of typal communities argue that distinct vegetation types develop at climax and are repeated over the landscape where environmental conditions are similar; (2) continuum advocates argue that even at climax, vegetation, like environmental conditions, varies continuously over the landscape (Daubenmire 1966; Cottam and McIntosh

1966; Vogl 1966). Some of those who accept the typal communities philosophy may view habitat type classification much the same as they view the taxonomic classification of the plant kingdom. Continuum advocates may regard habitat type classifications as an attempt to make categories by drawing fine lines at intervals along a complex vegetational continuum. Collier and others (1973) presented these contrasting philosophies and advocated an intermediate viewpoint.

While this debate may be of interest academically, it need not preoccupy natural resource managers and field biologists who need a logical, ecologically-based classification with which to work. We have proceeded under the philosophy that if a "continuum" does exist, then we would subdivide it into classes. Our primary objective has remained to develop a logical classification that reflects the natural patterns found on the landscape. Local conditions that deviate from this classification can still be described in terms of how they differ from the nearest typal description.

THE PHYSICAL SETTING

General Study Area

The physiography of the study area is generally characterized by several high, discontinuous mountain ranges of linear configuration that rise above surrounding valley and basin areas (fig. 1). The lowlands support many small communities and are mainly devoted to livestock production and other agricultural industries. Several large population centers are situated along the Wasatch Front. Thus, the nearby mountains are intensively utilized for forage, wood, recreation, and the paramount resource, water.

The study area has been considered part of two physiographic provinces (Fenneman 1931). The area to the east of Salt Lake City is a part of the Middle Rocky Mountain province. As such, it includes the most prominent features, the Uinta Mountains and the entire Wasatch Range, of which the Bear River Range, an eastern spur, extends some 50 miles into Idaho. The Basin and Range province encompasses the area immediately to the west of the Wasatch Range, including the smaller ranges to the west of Malad, Idaho. This is also the basic geographic separation for climatological descriptions of the study area (Brown 1960).

Floristically, Cronquist and others (1972) have considered the study area as the Uinta Mountains, the Wasatch Mountains, and the Great Basin "floristic divisions." Each division exhibits many distinct topographic, geologic, and climatic dissimilarities in addition to floristic ones. Indeed, the Uintas are more "Rocky Mountain" in all of these characters than is the Wasatch, a range that is more similar to those in the Great Basin (Cronquist and others 1972). As Cottam (1930) stated, "the Uinta Mountains represent Utah's only claim to a typical Northern Rocky Mountain flora." This is reflected prominently in the associations of vegetation in each respective area and therefore, their prevalent habitat types.

Because of these differences, the Uinta Mountains are largely treated throughout the discussion as a separate region of the study area. The smaller, islandlike ranges of the Great Basin are fairly similar to the western front of the Wasatch Range. The Great Basin and Wasatch Ranges, therefore, are collectively referred to as the "northwestern region."

Topography and Geology

The Wasatch Range trends north-south from near Soda Springs, Idaho, through north-central Utah to its terminus near Nephi; a distance of some 220 miles (355 km) (Cronquist and others 1972). Approximately two-thirds of the range lies within the study area (fig. 1).

Structurally, the Wasatch Range consists of a thrust-faulted and folded syncline that has been uplifted by block faulting. Uplift has been more active along the western edge, or front. Consequently, the western edge tends to be the summit of the Wasatch Range proper, as well as that of the Bear River Range. Rising above a series of western valley systems lying about 4,000 to 4,500 feet (1 220 to 1 370 m) elevation, summits attain nearly 10,000 feet (3 050 m) elevation in the north and nearly 12,000 feet (3 660 m) elevation in the south. Limited alpine vegetation occurs in the latter area.

The western edge is characterized by steep faces (facets) and ridges as well as deep, V-shaped westerly trending canyon systems, of which only the Weber and Provo Rivers cut across the range. The Bear River section, somewhat broader than the rest of the range, includes fairly extensive upland topography. Its eastern flank, dissected by smaller streams, slopes gently to the Bear Lake-Bear River valleys at about 6,000 feet (1 830 m) elevation.

The surface geologic formations are varied and oftentimes complex. Near Logan, Utah, early Paleozoic rocks (quartzite-sandstone-shales of marine origin as well as dolomite and limestone) form the canyon sides. At higher elevations, limestones and calcareous sandstones of carboniferous deposition are also common. Precambrian quartzite is quite common in Idaho as well as near Willard, Utah. Between Ogden and Salt Lake City, the narrow Wasatch Front consists mostly of complex Precambrian schist and gneiss. The southernmost portion of the Wasatch Range within the study area and that near Logan are geologically similar. Precambrian quartzite and argillite, and various Paleozoic and Mesozoic sedimentary rocks (both calcareous and noncalcareous) are represented.

Additionally, two other formations are especially noteworthy. First, intrusive Tertiary granitoid rocks occur in the Little Cottonwood Canyon area. Second, the Wasatch conglomerate is widespread from the Idaho-Utah border through the central and eastern flank areas of the Wasatch Range to northeast of Salt Lake City. Terrain is typically gentle to rolling uplands. This formation is comprised of quartzite and shale fragments and is of early Tertiary deposition (Williams 1946). It has been mapped by Stokes (1962), and Stokes and Madsen (1961) as the Knight conglomerate and occurs in the northwestern Uinta Mountains.

In topography and geology, the ranges of the Great Basin are similar to the Wasatch Range—with the possible exception of the Raft River Mountains. This minor range is geologically similar to the Uinta Mountains: an east-west orientation of some 25 miles (40 km), a core of Precambrian quartzite-schist-calcareous rocks, and local intrusions of Precambrian granitoids. Younger sedimentary rocks overlie its northwestern and eastern flanks.

Glaciation has occurred locally along the western crest of the Wasatch Range and in the Stansbury Mountains, leaving small cirques and drift as evidence (for example, at Tony Grove Lake near Logan). Glaciation has been most extensive southeast of Salt Lake City. There, glaciers formed typically large U-shaped canyons, with the glacier in Little Cottonwood Canyon extending downward to about 6,000 feet (1 830 m) elevation (Atwood 1909).

For Utah, the Uintas are almost an anomaly. Cronquist and others (1972, p. 152) have characterized the range as follows:

> The Uinta Mountains form an extensive east-west oriented anticlinal plateau, which for 100 miles rises above 9,000 feet elevation (55 miles of which is above 11,000 feet). The highest elevation is on Kings Peak at 13,498 feet.

These authors further note:

> The total area above timberline in the Uintas exceeds that of all the rest of the Intermountain Region combined. The extensive rolling hills of alpine country provide an environment for the development of a flora somewhat similar to that of the Arctic Region.

The central core of the anticline consists of Precambrian rocks. These are chiefly quartzite. Overlying sedimentary strata comprise the flanks. These include mainly Mississippian limestones and weakly calcareous sandstones (Kinney 1955) within the forested zones. Interbedded shales are locally common throughout both the core and flank areas. Several younger formations are especially significant, also.

The Duchesne formation, which was deposited during the late Eocene and which consists of fluvial sandstones of weathered quartzite as well as some mudstone, is represented chiefly west of the Whiterocks River. The quartziferous-dominated Browns Park formation of late Miocene or early Pliocene deposition occurs mainly east of the Uinta River. It forms gentle, locally extensive surfaces (Bradley 1964; Stokes and Madsen 1961).

Along the north-central flank, only limestones remain chiefly exposed. These occur as prominent, but discontinuous, moderate to steeply dipping sections that attain elevations of about 10,000 feet (3 050 m). Elsewhere, isolated evidence of late Oligocene or early Miocene pedimentation, which occurred in an arid or semiarid climatic regime, remains as the "Gilbert Peak surface" (Bradley 1964). Shallow bedrock is mainly associated with its upper extent, whereas the lower, more gentle extent is covered by an aggregated cobbly veneer of quartzite material. This extends well into the nonforested zone in Wyoming, which occurs below about 8,800 feet (2 680 m) elevation, and grades into the underlying Eocene-age shales of the Green River Basin.

The topography of the Uinta Mountains, then, is larg ly dominated by the above features. In addition, that o the more western and central areas has also been shape by the extensive glaciation of recent time. There, sever glaciers extended well into the surrounding basins. Those of the south slope cut very deep canyon systems whereas those of the north slope were less pronounced i this respect. Throughout, the higher elevations are characterized by cirques and narrow ridges, which form a scalloped crest, and large, drift-covered basins. Additionally, extensive interbasin, plateaulike surfaces rema in most areas. The largely unglaciated lower reaches of the southwestern and eastern Uintas are characterized by deep, V-shaped canyon topography similar to that o the Wasatch Range.

Contrasting plant communities often develop at the contact of calcareous and noncalcareous substrates throughout northern Utah and adjacent Idaho. Various situations have become apparent in the course of this study. These are discussed under the appropriate series and habitat types. Many instances are quite similar to those which have been noted for Montana (Pfister and others 1977), central Idaho through western Wyoming (Steele and others 1981, 1983), and north-central Wyoming (Hoffman and Alexander 1976). Pfister and others (1977, p.12) have also listed several, more local studies of such communities in and around Montana. But for the Uinta Mountains in general and for *Pinus contorta* and *Pseudotsuga menziesii* there in particular, Despain's (1973) study of the Big Horn Mountains, Wyo., is especially significant in this respect.

The Wasatch conglomerate is unique in its effect on plant communities. For example, much of this surface formation occurs well within the temperature range of *Pseudotsuga*, yet *Pseudotsuga* is not widely associated with this substrate. Instead, persistent *Populus tremuloides* communities of fire origin as well as variou nonforest communities dominate these sites. Whether this pattern represents an intolerance of *Pseudotsuga* t the soils or is related to past disturbance is uncertain. (On the other hand, some of the most productive sites for *Picea engelmannii* are associated with the highest occurrence of Wasatch conglomerates: the ABLA/PER h.t., PERA phase.)

Soils

The forested soils of northern Utah are diverse because of the typically steep mountain topography an in some areas recent glaciation. Many soils are rather gravelly and well drained; others are rocky and shallow Yet others are fairly deep and well developed, occupyin toe-slope positions or gentle to rolling terrain. A few a seasonally moist, such as those associated with stream side terraces or seasonally high water tables.

Wilson and others (1975) have compiled the major so associations of Utah, following the nomenclature of Soi **Taxonomy** (USDA Soil Conservation Service 1975). In general, the forest soils of northern Utah are represent by three broad soil groups, which are largely based on temperature and moisture regimen:

1. Group A.—Soils of the middle-to-high elevations that are cold (cryic temperature regime) and moist in

parts throughout the summer. These occur typically throughout the upper montane and subalpine climax series. Two associations are represented. The Argic Cryoborolls-Pachic Cryoborolls-Cryic Paleborolls Association (-1) is found throughout the northwestern region as well as in the westernmost Uinta Mountains, whereas the Typic Cryorthents-Typic Cryochrepts-Mollic Cryoboralfs Association (-4) occurs throughout the central and eastern Uintas.

2. Group B.—Soils of the lower-to-middle elevations that are usually moist in some parts during the summer (ustic moisture regime). These are restricted to the southern and northeastern Uinta Mountains. The Lithic Argiborolls-Rock Outcrop-Typic Argiborolls Association (-9) is mainly represented .

3. Group F.—Soils of the lower-to-middle elevations that are usually dry during the summer (xeric moisture regime). These are restricted to the northwestern region. The two most widely represented associations are the Lithic Haploxerolls-Typic Haploxerolls Association (-24) and the Pachic Argixerolls-Typic Argixerolls-Calcic Argixerolls Association (-25).

The authors discuss the general depth, textural, and pH characteristics of these soil associations. In addition, Lawton (1979) studied several environmental parameters of selected habitat types east of Logan, Utah, and identified several soils in these associations.

Climate and Microclimate

The climate of Utah is determined largely by elevation, latitude, and the principal storm patterns that track oceanic moisture into the State (Brown 1960). Given the rather narrow latitude encompassed by the study area (about 2°), climatic uniformity would be expected. Actually, the climates of the two regions are distinctly different, largely because of moisture patterns. This is expressed in their respective vegetation—and their habitat types.

Climatological data from stations that record both temperature and precipitation are presented in appendix D-2. In addition, precipitation data from two stations in the Uinta Mountains are presented. Although only a few stations are situated within the forested zone, the others allow general comparisons within northern Utah.

Temperature is influenced most strongly by elevation. Generally for Utah, mean annual temperature decreases about 3° F (1.7° C) for each 1,000-foot (305-m) increase in altitude, and decreases approximately 1.5° to 2.0° F (0.8° to 1.1° C) for each 1° increase in latitude (Brown 1960). Temperature and microclimate, however, can be greatly modified by slope exposure or cold air drainage or accumulation.

Two additional influences on temperature are locally present during the winter months. First, strong temperature inversions, ranging from 500 to 1,500 feet (150 to 455 m) in depth, develop in surrounding valleys as a result of down-slope cold air drainage and valley accumulation. Thus, temperatures of lower mountain slopes situated above the inversion layers can average between 9° and 18° F (5° to 10° C) higher than valley bottoms (Wilson and others 1975). Second, both the Great Salt Lake and Provo Lake have a mediating effect on the temperatures of nearby mountains (Brown 1960); these lakes also increase local precipitation by increasing the moisture content of the westerly storm systems.

The effect of latitude on temperature has special significance within the study area. *Abies concolor* has its northernmost Rocky Mountain location near Logan, Utah. As a viable climax, however, *A. concolor* essentially terminates much farther south in the vicinity of Ogden. Some possible temperature-latitude relationships that might influence species distribution are discussed under the *A. concolor* series.

The influx of oceanic moisture follows two general patterns. Throughout the winter and spring, the principal storm track flows westerly from the Pacific. Much of the moisture in this flow is lost in the Sierra Nevada area prior to reaching Utah. This flow is largely absent during the summer months, which creates an extended dry period, with the exception of local thunderstorms.

The second pattern is associated with moisture-laden air flowing into southeastern Utah from the Gulf of Mexico during the spring and summer months. This pattern usually penetrates only to the southern Uinta Mountains. There orographic storms regularly develop. For example, mean precipitation for the period of May to August is about 10 percent higher for the Uinta stations than for the Wasatch Range stations (appendix D-2). The occurrence of *Pinus ponderosa* (within its temperature limits) could reflect the distribution of this early growing season rainfall through the lower eastern Uintas to the northeastern area. Farther west, the high crest creates a rain shadow condition in local areas of the north-central slopes. There, *Pinus contorta* is frequently the indicated climax. Both of these vegetation patterns are discussed in more detail under each respective series.

Wind patterns also significantly influence vegetation. Windspeed usually varies with elevation and local topography, with upper slopes and ridgetops being most windy. Windspeed averages 15 to 20 miles per hour (24 to 32 km/h) at higher elevations, and about half of these values at lower elevations. Winds up to 90 miles per hour (145 km/h) accompany cold fronts, intense thunderstorms, and regional air movements (Wilson and others 1975). As Pfister (1972) has pointed out, the physiological stress induced by wind substantially reduces the effects of increased precipitation at higher elevations. Additionally, wind reduces snowpack accumulation on particularly exposed sites through wind erosion and sublimination. This is especially apparent where *Pinus flexilis* occurs; there, winter soil temperatures are also substantially lower (usually freezing) because of an absence of an insulating snowpack.

THE HABITAT TYPE CLASSIFICATION

A total of 36 habitat types are defined for northern Utah and adjacent Idaho. This large number of habitat types reflects the geologic and climatic relationships of the area to both the Great Basin and the Rocky Mountain system. In addition, the more common habitat types are divided into phases to further stratify the forested landscape.

The entire classification is listed in table 1 for convenient reference. Only scientific names are used in the text to prevent the confusion that might result from common names. However, common names of the categories are included in table 1, under each habitat type description heading, and in the checklist, appendix F. Frequent reference to type names requires the use of abbreviations; all follow a standard four-letter code, which consists of the first two letters of the genus and the first two letters of the species. Initially this code may be confusing, but it is easily mastered.

The classification is presented in the following order:

1. Key to the habitat types (fig. 3).—The first step in the correct identification of the habitat type is to become familiar with the instructions for the use of the key. The identification of the potential climax series, the habitat type, and finally the phase follows.
2. Series description.—This provides a general overview for each series and the habitat types. It usually includes a discussion of characteristics common to most of the habitat types within the series.
3. Habitat type description.—This information summarizes the geographic range, environmental features, vegetation, phases, and general management implications.

The series are discussed in an order that generally corresponds to an increasing moisture gradient and an increasing altitudinal gradient. Of course, not all series are encountered in any given location of the study area; the westernmost Uinta Mountains are the most diverse in this respect.

Under each series habitat types are presented in the order of their position in the key. Typically, the position of an indicator species in the key also reflects its relative ecological amplitude—species appearing first tend to have more restricted requirements and are on more moist sites than those appearing later. The order of habitat types usually reflects the relative extent of the type across the landscape, except that most of the last few types listed are minor in occurrence. Until the user gains experience with the classification, the identification of particularly awkward sites can be aided by this knowledge of indicator amplitudes and of the relative dryness of a site.

The extent of the habitat types is indicated by relative terms. "Incidental" types occur as isolated extensions of types that reportedly are more common in other areas, such as ABLA/STAM. "Local," or "minor," habitat types are either prevalent in specific locations within the study area (for example, ABLA/CARU) or widespread in occurrence but do not occupy extensive area throughout a region or the entire study area (ABLA/CACA). "Major" habitat types are both widely distributed and extensive (PSME/BERE, ABLA/BERE and ABLA/VASC).

Figure 3.—Key to climax series, habitat types, and phases.

READ THESE INSTRUCTIONS FIRST!

1. Use this key for stands with a mature tree canopy that are not severely disturbed by grazing, logging, forest fire, etc. (If the stand is severely disturbed or in an early successional stage, the habitat type can best be determined by extrapolating from the nearest mature stand occupying a similar site.)
2. Accurately identify and record canopy coverages for all indicator species (appendix F). Canopy coverage is the nearest percentage of cover, from 1 to 10 percent and the nearest 5 percent thereafter. If a species is present with a 0.5 percent cover and is not obviously restricted to atypical microsites, record a "T" for trace.
3. Check plot data in the field to verify that the plot is representative of the stand as a whole. If not, take another plot.
4. Identify the correct potential climax tree species in the Series key. (Generally, a tree species is considered reproducing successfully if 10 or more individuals per acre [25 per hectare] occupy or will occupy the site.)
5. Within the appropriate series, key to HABITAT TYPE by following the key literally. Determine the phase by matching the stand conditions with the phase descriptions for the type. (The first phase description that fits the stand is the correct one.)
6. If you have difficulty deciding between types, refer to constancy and coverage data (appendix C-1) and the habitat type descriptions.
7. In stands where undergrowth is obviously depauperate (unusually sparse) because of dense shading or litter accumulations, reduce the critical key coverage levels from 1 percent to "present" and 5 percent to 1 percent.
8. Remember, the key is NOT the classification! Validate the determination made using the key by checking the written description.

Key to Climax Series

(DO NOT PROCEED UNTIL YOU HAVE READ THE INSTRUCTIONS!)

1. *Abies lasiocarpa* present and reproducing successfully .... *Abies lasiocarpa* Series (Item H)
1. *Abies lasiocarpa* not the indicated species 2

    2. *Abies concolor* present and reproducing successfully .... *Abies concolor* Series (Item E)
    2. *Abies concolor* not the indicated climax 3

3. *Picea engelmannii* present and reproducing successfully .... *Picea engelmannii* Series (Item F)
3. *Picea engelmannii* not the indicated climax 4

    4. *Picea pungens* present and reproducing successfully .... *Picea pungens* Series (Item D)
    4. *Picea pungens* not the indicated climax 5

5. *Pinus flexilis* a successfully reproducing dominant, often sharing that status with *Pseudotsuga* .... *Pinus flexilis* Series (Item A)
5. *Pinus flexilis* absent or clearly seral 6

    6. *Pseudotsuga menziesii* present and usually reproducing successfully .... *Pseudotsuga menziesii* Series (Item C)
    6. *Pseudotsuga menziesii* not the indicated climax 7

7. *Pinus ponderosa* present and reproducing successfully .... *Pinus ponderosa* Series (Item B)
7. *Pinus ponderosa* not the indicated climax 8

    8. Pure *Pinus contorta* stands with little evidence as to potential climax .... *Pinus contorta* Series (Item G)
    8. *Pinus contorta* absent; *Populus tremuloides* present .... *Populus tremuloides* Series (Unclassified)

(con.)

Figure 3.—(con.)

A. Key to *Pinus flexilis* Habitat Types

1. *Cercocarpus ledifolius* at least 5% cover (and persistent)	*Pinus flexilis/Cercocarpus ledifolius* h.t. (p. 20)
1. *C. ledifolius* less than 5% cover or clearly seral	2
2. *Berberis repens* at least 1% cover.	*Pinus flexilis/Berberis repens* h.t. (p. 21)
2. *B. repens* less than 1% cover; *Leucopoa kingii* present	*Pinus flexilis/Leucopoa kingii* h.t. (p. 20)

B. Key to *Pinus ponderosa* Habitat Types

1. *Carex geyeri* at least 5% cover	*Pinus ponderosa/Carex geyeri* h.t. (p. 22)
1. Not as above; *Festuca idahoensis* or *F. ovina* present	*Pinus ponderosa/Festuca idahoensis* h.t. (p. 22)
a. *Arcostaphylos patula* at least 5% cover	*Arctostaphylos patula* phase
b. *Artemisia tridentata* at least 5% cover	*Artemisia tridentata* phase
c. Not as above	*Festuca idahoensis* phase

C. Key to *Pseudotsuga menziesii* Habitat Types

1. *Physocarpus malvaceus* at least 5% cover	*Pseudotsuga menziesii/Physocarpus malvaceus* h.t. (p. 25)
1. *P. malvaceus* less than 5% cover	2
2. *Acer glabrum* at least 5% cover	*Pseudotsuga menziesii/Acer glabrum* h.t. (p. 26)
2. *A. glabrum* less than 5% cover	3
3. *Osmorhiza chilensis* or *O. depauperata* at least 5% cover either separately or collectively	*Pseudotsuga menziesii/Osmorhiza chilensis* h.t. (p. 26)
3. *O. chilensis* or *O. depauperata* less than 5% cover	4
4. *Calamagrostis rubescens* at least 5% cover	*Pseudotsuga menziesii/Calamagrostis rubescens* h.t. (p. 27)
4. *C. rubescens* less than 5% cover	5
5. *Cercocarpus ledifolius* at least 5% cover	*Pseudotsuga menziesii/Cercocarpus ledifolius* h.t. (p. 27)
5. *C. ledifolius* less than 5% cover	6
6. *Berberis repens* or *Pachistima myrsinites* at least 1% cover	*Pseudotsuga menziesii/Berberis repens* h.t. (p. 28)
a. *Carex geyeri* at least 5% cover	*Carex geyeri* phase
b. *Juniperus communis* at least 5% cover	*Juniperus communis* phase
c. *Symphoricarpos oreophilus* at least 5% cover and *Leucopoa kingii* usually present, stands isolated or never achieving closed canopies	*Symphoricarpos oreophilus* phase
d. Not as above	*Berberis repens* phase
6. *B. repens* and *P. myrsinites* less than 1% cover; *Symphoricarpos oreophilus* present (and usually greater than 5% cover)	*Pseudotsuga menziesii/Symphoricarpos oreophilus* h.t. (p. 30)

(con.)

Figure 3.—(con.)

D. Key to *Picea pungens* Habitat Types

1. *Equisetum arvense* at least 5% cover .... *Picea engelmannii/Equisetum arvense* h.t. (p. 36)
1. *E. arvense* less than 5% cover 2

    2. *Agropyron spicatum* at least 1% cover .... *Picea pungens/Agropyron spicatum* h.t. (p. 32)
    2. *A. spicatum* less than 1% cover; *Berberis repens* or *Juniperus communis* present .... *Picea pungens/Berberis repens* h.t. (p. 32)

E. Key to *Abies concolor* Habitat Types

1. *Physocarpus malvaceus* at least 10% cover .... *Abies concolor/Physocarpus malvaceus* h.t. (p. 34)
1. *P. malvaceus* less than 10% cover 2

    2. *Osmorhiza chilensis* at least 10% cover (or riparian tree species present) .... *Abies concolor/Osmorhiza chilensis* h.t. (p. 34)
    2. Not as above; *Berberis repens* or *Pachistima myrsinites* present .... *Abies concolor/Berberis* repens h.t. (p. 34)

        a. *Symphoricarpos oreophilus* at least 5% cover or stands isolated or never achieving closed canopy .... *Symphoricarpos oreophilus* phase
        b. Not as above .... *Berberis repens* phase

F. Key to *Picea engelmannii* Habitat Types

1. *Equisetum arvense* at least 5% cover .... *Picea engelmannii/Equisetum arvense* h.t. (p. 36)
1. *E. arvense* less than 5% cover 2

    2. *Calamagrostis canadensis* at least 5% cover .... *Abies lasiocarpa/Calamagrostis canadensis* h.t. (p. 40)
    2. *C. canadensis* less than 5% cover 3

3. *Caltha leptosepala* at least 1% cover .... *Picea engelmannii/Caltha leptosepala* h.t. (p. 37)
3. *C. leptosepala* less than 1% cover 4

    4. *Vaccinium caespitosum* at least 1% cover .... *Picea engelmannii/Vaccinium caespitosum* h.t. (p. 37)
    4. *V. caespitosum* less than 1% cover 5

5. *Vaccinium scoparium* at least 5% cover .... *Picea engelmannii/Vaccinium scoparium* h.t. (p. 38)
5. *Vaccinium scoparium* less than 5% cover 6

    6. *Ribes montigenum* present .... *Abies lasiocarpa/Ribes montigenum* h.t. (p. 51)
    6. *R. montigenum* absent; *Juniperus communis* the major undergrowth species .... *Abies lasiocarpa/Juniperus communis* h.t. (p. 54)

(con.)

Figure 3.—(con.)

G. Key to *Pinus contorta* Communities

1. *Calamagrostis canadensis* at least 5% cover	*Pinus contorta/Calamagrostis canadensis* c.t. (p. 56)
1. *C. canadensis* less than 5% cover	2
2. *Vaccinium caespitosum* at least 1% cover	*Pinus contorta/Vaccinium caespitosum* c.t. (p. 56)
2. *V. caespitosum* less than 1% cover.	3
3. *Vaccinium scoparium* at least 5% cover	*Pinus contorta/Vaccinium scoparium* h.t. (p. 57)
3. *V. scoparium* less than 5% cover	4
4. *Calamagrostis rubescens* at least 5% cover	*Abies lasiocarpa/Calamagrostis rubescens* h.t. (p. 45)
4. *C. rubescens* less than 5% cover	5
5. Stands of the south-central Uintas; *Juniperus communis* (or *Arctostaphylos patula*) the dominant undergrowth	*Pinus contorta/Juniperus communis* h.t. (p. 58)
5. Not as above	6
6. *Arctostaphylos uva-ursi* at least 1% cover	*Pinus contorta/Arctostaphylos uva-ursi* h.t. (p. 58)
6. *A. uva-ursi* less than 1%	7
7. *Berberis repens* or *Pachistima myrsinites* present	*Pinus contorta/Berberis repens* c.t. (p. 59)
7. *B. repens* and *P. myrsinites* absent	*Pinus contorta/Carex rossii* h.t. (p. 60)

H. Key to *Abies lasiocarpa* Habitat Types

1. *Equisetum arvense* at least 5% cover	*Picea engelmannii/Equisetum arvense* h.t. (p. 36)
1. *E. arvense* less than 5% cover	2
2. *Calamagrostis canadensis* at least 5% cover	*Abies lasiocarpa/Calamagrostis canadensis* h.t. (p. 40)
2. *C. canadensis* less than 5% cover	3
3. *Streptopus amplexifolius* or *Senecio triangularis* at least 5% cover either separately or collectively	*Abies lasiocarpa/Streptopus amplexifolius* h.t. (p. 41)
3. Not as above	4
4. *Caltha leptosepala* at least 1% cover	*Picea engelmannii/Caltha leptosepala* h.t. (p. 37)
4. *C. leptosepala* less than 1% cover	5
5. *Actaea rubra* at least 5% cover	*Abies lasiocarpa/Actaea rubra* h.t. (p. 41)
5. *A. rubra* less than 5% cover	6
6. *Physocarpus malvaceus* at least 5% cover	*Abies lasiocarpa/Physocarpus malvaceus* h.t. (p. 41)
6. *P. malvaceus* less than 5% cover	7
7. *Acer glabrum* or *Sorbus scopulina* at least 5% cover either separately or collectively	*Abies lasiocarpa/Acer glabrum* h.t. (p. 42)
7. Not as above	8
8. *Vaccinium caespitosum* at least 1% cover	*Abies lasiocarpa/Vaccinium caespitosum* h.t. (p. 42)
8. *V.caespitosum* less than 1% cover	9

(con.)

Figure 3.—(con.)

9. *Vaccinium globulare* at least 5%	*Abies lasiocarpa/Vaccinium globulare* h.t. (p. 43)
9. *V. globulare* less than 5% cover	10
10. *Vaccinium scoparium* at least 5% cover	*Abies lasiocarpa/Vaccinium scoparium* h.t. (p. 44)
a. *Arnica latifolia* at least 1% cover	*Arnica latifolia* phase
b. *Carex geyeri* at least 5% cover	*Carex geyeri* phase
c. Not as above	*Vaccinium scoparium* phase
10. *V. scoparium* less than 5% cover	11
11. *Calamagrostis rubescens* at least 5% cover	*Abies lasiocarpa/Calamagrostis rubescens* h.t. (p. 45)
11. *C. rubescens* less than 5% cover	12
12. *Pedicularis racemosa* at least 1% cover and *Ribes montigenum* or *Pinus flexilis* absent	*Abies lasiocarpa/Pedicularis racemosa* h.t. (p. 46)
a. *Pseudotsuga menziesii* present	*Pseudotsuga menziesii* phase
b. Not as above	*Pedicularis racemosa* phase
12. Not as above	13
13. *Berberis repens* or *Pachistima myrsinites* present	*Abies lasiocarpa/Berberis repens* h.t. (p. 47)
a. *Pinus flexilis* a dominant overstory component	*Pinus flexilis* phase
b. *Ribes montigenum* present	*Ribes montigenum* phase
c. *Carex geyeri* at least 5% cover	*Carex geyeri* phase
d. *Juniperus communis* at least 5% cover	*Juniperus communis* phase
e. *Pseudotsuga menziesii* present	*Pseudotsuga menziesii* phase
f. Not as above	*Berberis repens* phase
13. Not as above	14
14. *Ribes montigenum* present	*Abies lasiocapra/Ribes montigenum* h.t. (p. 51)
a. *Trisetum spicatum* present; stands of the upper timber-line zone	*Trisetum spicatum* phase
b. *Pinus contorta* a major over-story component; stands of the south-central Uinta Mountains	*Pinus contorta* phase
c. *Thalictrum fendleri* present	*Thalictrum fendleri* phase
d. Not as above	*Ribes montigenum* phase
14. *R. montigenum* absent	15
15. *Osmorhiza chilensis* or *O. depauperata* at least 1% Cover either separately or collectively	*Abies lasiocarpa/Osmorhiza chilensis* h.t. (p. 53)
15. Not as above; *Juniperus communis* the major Undergrowth species	*Abies lasiocarpa/Juniperus communis* h.t. (p. 54)

Pinus flexilis Series

Distribution.—This series has a limited distribution in northwestern Utah and adjacent Idaho, occurring principally in the northern Wasatch Range. Stands are found on all aspects but normally occupy south- to west-facing slopes or ridgetops of about 7,000 feet (2 135 m) to above 8,700 feet (2 650 m) elevation. These exposures represent some of the most adverse environments for tree growth within the *Abies lasiocarpa* and upper *Pseudotsuga menziesii* zones. In this respect, the *Pinus flexilis* series represents a topographic or edaphic climax.

Vegetation.—In northwestern Utah, stands of this series do not usually have *Pinus flexilis* as the only tree species present: more often *Pseudotsuga* is a climax associate. Normally *Pinus flexilis* is a successfully reproducing dominant with no indication of being replaced at climax. Stands have trees that occur either singly or in scattered groups. Recent evidence indicates that *Pinus flexilis* establishment throughout much of this series is the result of abandoned seed caches of the Clark's nutcracker (Lanner and Vander Wall 1980).

Undergrowth is typically shrubby. Principal species include *Symphoricarpos oreophilus, Berberis repens*, and various Asteraceae and bunchgrasses, species which are also commonly representative of adjacent, drier nonforest communities (Ream 1964). In addition, where *Cercocarpus ledifolius* is persistent, undergrowth is often impenetrably dense. Adjacent, more moderate exposures are the PSME/CELE or PSME/BERE h.t.'s.

Soils/climate.—This series occurs on calcareous and shaley-quartziferous substrates, which are often considerably exposed at the surface (appendix D). Soils are correspondingly shallow and gravelly, and surface textures range from sandy loam to clayey. Loose surface rock and bare soil are also typically present. Erosion of fine particles is usually evident. Litter accumulation is often intermittent and shallow; litter depth for the series averages 0.6 inches (1.6 cm).

Exposures are droughty, relatively warm (but with high diurnal and seasonal temperature differences) and subject to year-long dessicating winds. In addition to accelerating evapotranspiration, these winds substantially reduce snowpack accumulation. Soils commonly freeze and have low moisture-holding capacity. Lack of soil moisture is somewhat ameliorated, however, by the fractured bedrock which provides a deeper rooting medium. (Climatological data are unavailable.)

Fire history.—Evidence of past fires is scant. Light surface fires likely occurred, but their effect on undergrowth was probably inconsequential.

Productivity/management.—This series is important watershed cover and also provides cover and browse for deer in the summer, particularly where *Cercocarpus* is vigorous and accessible. Livestock use the type primarily for shade wherever the more open stands are near forage areas. *Pinus flexilis* seeds, which are relatively large, supply a critical food source for small mammals and birds.

Timber productivity is very low to low (appendix E). This is attributed to sporadic regeneration, stockability limitations, and poor growth.

Other studies.—*Pinus flexilis* habitat types have been described in Montana by Pfister and others (1977); central Idaho by Steele and others (1981); eastern Idaho and western Wyoming by Steele and others (1983); and southeastern Wyoming by Wirsing and Alexander (1975).

Other various *Pinus flexilis* habitats have been described in the Bighorn Mountains of Wyoming (Despain 1973); New Mexico, Colorado and southeastern Wyoming (Peet 1978); and Utah (Ellison 1954; Pfister 1972; Ream 1964).

The *Pinus flexilis/Leucopoa kingii* h.t. (*Hesperochola kingii*), described by Steele and others (1983) and Wirsing and Alexander (1975), may be present in northwestern Utah. Specific considerations are discussed for the PIFL/CELE and PIFL/BERE h.t.'s.

PINUS FLEXILIS/CERCOCARPUS LEDIFOLIUS H.T.(PIFL/CELE; LIMBER PINE/CURLLEAF MAHOGANY)

Distribution.—This habitat type occurs mainly in the northern Wasatch Range. The most common exposures are southerly to westerly upper slopes and ridgetops between about 7,000 and 8,700 feet (2 135 and 2 650 m) elevation.

Vegetation.—*Pinus flexilis* is the indicated climax, usually with *Pseudotsuga* as a climax associate. Normally, old-growth stands are open (fig. 4).

Figure 4. *Pinus flexilis/Cercocarpus ledifolius* h.t. on a gentle southeasterly slope toward the north end of the Bear River Range on the Wasatch-Cache National Forest (7,300 feet [2 230 m] elevation). *Artemisia tridentata* and *C. ledifolius* are prominent shrubs among the scattered *P. flexilis*; the herb layer is dominated by the grasses *Leucopoa kingii* and *Stipa lettermannii*.

Undergrowth is characterized by persistent *Cercocarpus* constituting variable but conspicuous cover. Other shrubs are *Artemisia tridentata, Berberis repens, Chrysothamnus viscidiflorus, Pachistima myrsinites*, and *Symphoricarpos oreophilus*. Common herbaceous species include *Achillea millefolium, Balsamorhiza sagittata,*

Comandra pallida, Eriogonum spp., *Lomatium nuttallii, Agropyron spicatum, A. trachycaulum, Leucopoa kingii,* and *Stipa lettermannii.*

Soils.—Soils are as described for the series.

Productivity/management.—The habitat type is primarily valued as deer summer range and watershed protection. Timber productivity is low (appendix E). Nevertheless, *Pinus* can attain massive diameters of 40+ inches (100+ cm) and exceed 500 years age, but heights are considerably less than those for *Pseudotsuga.*

A deviation in the site-index analysis should be noted. For this habitat type only, average site index represents values obtained mainly from old-growth trees (computed at 200 years age). These estimates appear to be reasonable because other sample trees in the same stand meeting the age criterion have values slightly below those of the old-growth trees.

Other studies.—PIFL/CELE was described in east-central Idaho by Steele and others (1981). It was also noted in eastern Idaho (Steele and others 1983).

The ridgetop sites located on the eastern flank of the Wasatch Range near Paris, Idaho, are physionomically similar to the PIFL/LEKI h.t., described by Steele and others (1983) and Wirsing and Alexander (1975). Undergrowth, however, has persistent *Cercocarpus* but is otherwise more steppelike, including abundant *Artemisia tripartita.* Such sites are common only to this locality and probably reflect a regional transition between the PIFL/LEKI and PIFL/CELE h.t.'s.

PINUS FLEXILIS/BERBERIS REPENS H.T. (PIFL/BERE; LIMBER PINE/OREGONGRAPE)

Distribution.—PIFL/BERE is a rather uncommon habitat type that occurs in the northern Wasatch Range in the vicinity of Logan, Utah. It occurs on steep, southerly slopes and ridgetops near 7,000 feet (2 135 m) elevation, and at lower elevations (to 6,500 feet [1 982 m]) on northerly exposures.

Vegetation.—*Pinus flexilis* is the indicated climax, and *Pseudotsuga* is often a climax codominant. *Juniperus scopulorum* is locally a minor seral associate.

Undergrowth is shrubby, being dominated by *Berberis repens, Pachistima myrsinites, Prunus virginiana,* and *Symphoricarpos oreophilus.* Herbaceous species include *Comandra pallida, Mertensia oblongifolia, Senecio integerrimus, Viola purpurea, Agropyron spicatum, A. trachycaulum, Leucopoa kingii,* and occasionally *Elymus cinereus* as well.

Soils.—Soils are as described for the series, although they are somewhat more protected from environmental fluctuations. Also, bare soil is less than that of the PIFL/CELE h.t. and litter is somewhat more uniform.

Productivity/management.—Principal uses are as deer summer range and watershed cover. Timber productivity is very low to low (appendix E) because of stockability limitations. Site index, however, appears to be significantly higher than that in the PIFL/CELE h.t., particularly for *Pseudotsuga.*

Other studies.—The PIFL/BERE h.t. has not been identified previously in the literature. Undergrowth is somewhat similar compositionally to that of the PIFL/HEKI h.t. of eastern Idaho and western Wyoming (Steele and others 1983), but undergrowth structure and site exposures are not physiognomically similar.

Pinus ponderosa Series

Distribution.—Sites having *P. ponderosa* as the indicated climax occur primarily in the eastern and southern Uinta Mountains.[1] There, the series occupies warm and dry exposures through a rather narrow altitudinal belt: this is summarized in table 3. Generally, soils are well drained and sandy. The series is seldom found on clayey soils or those derived from limestone. Topography is typically gentle in the northeastern area where the series occurs between about 7,100 and 8,400 feet (2 165 and 2 560 m) elevation. In the southern areas, however, the series occurs on steeper topography between about 8,100 and 8,900 feet (2 470 and 2 715 m) elevation.

Climatic factors strongly influence the distribution of the series. Its geographic extent is generally associated with the prevailing patterns of greatest early growing season precipitation. On droughty soils, minimum season temperatures influence the upper elevation limits of this series.

P. ponderosa is also found in the western Uintas, particularly near Kamas, Utah, and in very isolated locations in the Wasatch Range as well. This species sometimes appears to be seral in these areas. A few of these stands are experimental plantations that date in origin from 1913 to 1920 (Baker and Korstian 1931).

The *Pinus contorta* series, and locally the *Pseudotsuga* and *Picea pungens* series, are adjacent to or above this series on the more moist or colder exposures, or on limestone substrates. The *P. ponderosa* series is normally bounded at the warmer and drier extent by various shrub, grassland, or woodland communities.

Vegetation.—The structure of mature stands varies from rather open to locally dense. Likewise, age structure ranges from all-aged to irregular even-aged groups or completely even-aged stands. *Pinus contorta* and *Populus tremuloides* are the most significant seral associates (appendix B).

Graminoids are normally conspicuous in the undergrowth, and various shrub species are dominant in certain parts of the series. Physiognomically, undergrowth of the PIPO/CAGE h.t. is similar to *Carex geyeri*-dominated undergrowths of the other series. Undergrowth of the FEID phase of the PIPO/FEID h.t., however, is altogether unique in northern Utah; it is an open forest-grassland.

Soils/climate.—This series is generally associated with quartzite parent materials, except in the southern area where it is also associated with sandstone (appendix D). The well-drained, gravelly soils are shallow when over bedrock, but deeper when developed from various depositional features. The latter soils are more common in the

[1]Sites must be additionally capable of supporting mature stands that have an aggregate overstory canopy coverage of at least 25 percent, excluding woodland species (*Pinus edulis, Juniperus,* and *Quercus gambelii*). Note that woodlands having *P. ponderosa* as a component are unclassified.

lower southern areas. Most surface soils are sandy loams or loams. Exposed surface rock is greater in the south, but normally bare soil is absent throughout. Litter depth is fairly uniform.

No weather stations exist within the series. Data from Flaming Gorge, however, located below the series in a *Pinus-Juniperus* woodland community, are presented in appendix D-2.

Fire history.—Fires were undoubtedly frequent in the past. Large *P. ponderosa* are resistant to surface fires, but fire will kill or damage seedlings and smaller trees. Destructive crown fires sometimes occur in dense stands of young trees. Thus, fire locally shapes stands and, conversely, stand structure can influence significantly burning patterns and intensity.

Fire effects do not long persist in undergrowth that is principally herbaceous. But where chaparral-like undergrowth occurs, as in the PIPO/FEID h.t., ARPA phase, fire can greatly affect local composition and structure for some time. Different shrub species react differently to fire. For instance, ecotypes of *Purshia tridentata* may be killed outright by light surface fires, but usually reseed easily. *Arctostaphylos* regenerates readily following a necessary seed scarification by fire and may also resprout from surviving root crowns, as it does in parts of Oregon (Franklin and Dyrness 1973). Frequent fires, then, would tend to result in the development of a dense, shrubby undergrowth that would persist under conditions of less than maximum overstory density.

Productivity/management.—Timber productivity ranges from very low to low (appendix B). This is largely because of stockability limitations. PIPO/CAGE is generally the most productive habitat type of the series.

Opportunities for timber management are generally good for the more moderate sites. Throughout the *P. ponderosa* series, however, relatively intense competition from undergrowth vegetation as well as relatively unfavorable soil moisture conditions greatly retard seedling establishment; this is further compounded by infrequent seed production. But when all factors are favorable, especially summer precipitation, *P. ponderosa* readily regenerates. As Wellner and Ryker (1973) suggest, the multitude of stand conditions present in the series usually provide several viable strategies for natural regeneration: methods include selection, shelterwood, and small clearcuts. Some site preparation might be necessary for all. Also, artificial regeneration may be successful on the better sites.

Where sites are less brushy, this series provides good forage for domestic livestock. Deer use for browse and as cover is moderate.

Other studies.—Various *Pinus ponderosa* habitat types have been described from the Northern Rocky Mountains (Daubenmire and Daubenmire 1968; Hoffman and Alexander 1976; McLean 1970; Pfister and others 1977; Steele and others 1981; Thilenius 1972; Wirsing and Alexander 1975). In addition, Franklin and Dyrness (1973) have summarized the *P. ponderosa* communities of the Northwestern United States, many of which have *P. ponderosa* as the indicated climax.

PINUS PONDEROSA/CAREX GEYERI H.T. (PIPO/CAGE; PONDEROSA PINE/ELKSEDGE)

Distribution.—This habitat type, the most moist in the series, is apparently restricted in distribution to the northeastern Uinta Mountains where it occupies gentle slopes. Elevational range and exposures are summarized in table 3.

Vegetation.—*Pinus ponderosa* is the indicated climax. *Pseudotsuga menziesii* is accidental. Normally canopies are moderately dense and stands are even-aged or are comprised of groups of different ages.

Undergrowth is characterized by a prominent ground cover of *Carex geyeri*. Other species common in the type include *Amelanchier alnifolia, Berberis repens, Pachistima myrsinites, Symphoricarpos oreophilus, Antennaria* spp., and *Poa nervosa*. Herbaceous species are normally inconspicuous, however.

Cooler adjacent sites are generally occupied by the PSME/BERE h.t., CAGE phase, or *Pinus contorta* communities. The latter communities also occupy nearby sites having shallower soils or those with greater gravel content. In addition, *Arctostaphylos uva-ursi* is occasionally abundant, reflecting a transition to the drier and perhaps more frost-prone PICO/ARUV h.t.

Soils.—Our sample stands are associated with some of the deeper, more developed montane soils encountered in the northeastern Uinta Mountains. Substrates are quartzite (appendix D). Soil surface textures are sandy loam or loamy, and normally gravel is present. Surface rock and bare soil are typically absent. Litter depth averages 1.8 inches (2.9 cm).

Productivity/management.—Timber productivity is low (appendix E). Average sample site index is the highest in the series, but stockability limitations reduce productivity. Even-aged management of *Pinus* by shelterwoods or small clearcuts appears to be the most feasible option for most sites. Also, site preparation may be necessary to reduce early competition from *C. geyeri*.

Deer use for cover is moderate. Domestic livestock use is low. Overstory manipulation should increase forage production, resulting in increased ungulate use.

Other studies.—The PIPO/CAGE h.t. was first described by Wirsing and Alexander (1975) in the Medicine Bow National Forest of southeastern Wyoming. It was most extensive in the Laramie Peak area but was absent from the Sierra Madre area, the area closest to the Uinta Mountains. This habitat type has not been described in other studies.

PINUS PONDEROSA/FESTUCA IDAHOENSIS H.T. (PIPO/FEID; PONDEROSA PINE/IDAHO FESCUE)

Distribution.—This is the most common habitat type in this series, occurring in the northeastern and south-central areas of the Uinta Mountains. In general, exposures are warm and dry, and elevations range from 7,100 to 8,400 (2 165 to 2 560 m) in the northeast and from 8,100 to 8,900 feet (2 470 to 2 715 m) in the south-central area. Three phases are recognized; a more detailed summarization of elevation and exposure by phase and area of occurrence is presented in table 3.

Table 3.—Distribution of the PIPO/CAGE h.t. and phases of the PIPO/FEID h.t. in different geographic areas of the Uinta Mountains

Habitat type	Northeastern		South-central	
	Elevation range	Exposure	Elevation range	Exposure
	Feet (m)		*Feet (m)*	
PIPO/CAGE	7,200-8,300 (2 195-2 530)	NW-SE	None	
PIPO/FEID-ARPA	None		8,100-8,900 (2 470-2 715)	W,NE-S
PIPO/FEID-ARTR	7,500-8,300 (2 285-2 530)	W-N,SE	8,300 (2 530)	SE
PIPO/FEID-FEID	7,100-8,400 (2 165-2 560)	NW-SE	8,200-8,600 (2 500-2 620)	E-S-W

Vegetation.—*Pinus ponderosa* is the indicated climax; on some sites it is also the only tree species present. *Pseudotsuga* is accidental. The seral species *Pinus contorta, Populus tremuloides*, and *Juniperus scopulorum* differ in importance and distribution by phase (appendix B). Stand structure varies from very open to rather dense, and from all-aged to even-aged.

Depending on the phase, the undergrowth ranges from densely brushy to depauperate. *Festuca idahoensis* and/or *F. ovina* generally dominate the herbaceous component (fig. 5), although *Poa fendleriana* sometimes dominates in the south-central area. Other common graminoids are *Carex rossii* and *Sitanion hystrix*. Shrub species usually encountered throughout the type include *Amelanchier alnifolia, Artemisia tridentata vaseyana, Berberis repens*, and *Juniperus communis*. The more droughty sites also have *Amelanchier utahensis* and *Cercocarpus montanus*, the latter being more local in occurrence. Forb composition is generally diverse, but the species are usually inconspicuous; *Antennaria* spp. and *Heterotheca villosa* are notable exceptions.

***Arctostaphylos patula* (ARPA) phase.**—This warm, dry phase was found only in the south-central area where some sites occupy the highest elevations of the series (table 3). Topography is variable but includes primarily gentle terrain, and steep northeasterly slopes and ridgetops.

Pinus contorta and *Populus* are the principal seral associates. Each has a local distribution but only the latter is of major importance.

Undergrowth is normally brushy. It is usually dominated by the typal shrub *A. patula, Purshia tridentata*, and *Symphoricarpos oreophilus*. Common herbs include *Arenaria congesta* and *Sedum lanceolatum*.

Adjacent warmer sites often support shrub communities dominated by *A. patula* and *Amelanchier*. Cooler nearby sites are generally occupied by the FEID phase of this h.t. or the PICO/JUCO c.t.

***Artemisia tridentata* (ARTR) phase.**—This phase occurs mostly in the northeast area. It occupies gentle, sloping tablelands and ridges, and generally lies immediately above *Artemisia*/graminoid communities, which are common to this area. Overall, exposures tend to be more westerly than those of the FEID phase.

Figure 5. *Pinus ponderosa/Festuca idahoensis* h.t. on the eastern end of the Uinta Mountains (7,700 feet [2 360 m] elevation), Ashley National Forest. The undergrowth consists of an abundance of *F. idahoensis*, and widely scattered *Artemisia tridentata* and *Purshia tridentata*.

Pinus ponderosa occurs in groups or as scattered individuals. *Juniperus scopulorum* is a local, minor seral species. Canopies are more closed wherever *P. contorta* and *Populus* occur as important components.

Undergrowth is variable, but generally shrubby and characterized by *Artemisia tridentata vaseyana*. This species has its greatest abundance in this phase, as does *Festuca idahoensis* on some sites. *Purshia* and *Symphoricarpos* are usually present in addition to the typal species.

***Festuca idahoensis* (FEID) phase.**—This phase is common in both areas of the Uinta Mountains.

In the northeast it is locally extensive above 7,800 feet (2 375 m) elevation, occupying gentle tablelands or

slopes that generally have more easterly exposures than the drier ARTR phase. Most often adjacent nonforest sites support shrub/bunchgrass communities.

Pinus contorta and *Populus* are local, minor seral associates in this area. Undergrowth varies from moderately dense in cover to depauperate. It is dominated by graminoids of which *Festuca* and *Poa nervosa* are the most common; the other typal species are usually subordinate.

The FEID phase in the south-central area occurs in a narrow belt 8,200 to 8,600 feet (2 500 to 2 620 m) elevation, occupying moderate to steep hillslopes and ridges. Exposures tend to be more southerly than those of the ARPA phase.

Juniperus scopulorum is occasionally present with *Pinus ponderosa*, and canopies are somewhat more closed than those of the other phases. Undergrowth tends to be more brushy with less diversity of species: typically, *Poa fendleriana* is the dominant member of the typal species.

Soils.—Sampled stands primarily have sandstone or quartzite parent materials (appendix D), and occupy a variety of broad regolith types. South-central stands are associated with glacial outwash, ground moraine, alluvium, and residual bedrock, whereas the northeast stands are found only on residual bedrock. Surface soil textures are sandy loam to loamy, and gravel is typically present in considerable amounts. Surface rock varies in amount, ranging from absent to very considerable; the south-central stands are more rocky. Little if any bare soil is present in the type. Litter depth is greatest in the south-central stands, where it averages 1.5 inches (3.9 cm) for both the ARPA and FEID phases.

The ARTR and FEID phases on the northeastern area have average litter depths of 0.9 and 0.7 inches (2.4 and 1.7 cm) respectively. The average depth for the habitat type is 1.1 inches (2.9 cm).

Productivity/management.—Timber productivity is low to very low (appendix E). Sample site index, stockability limitations, regeneration difficulties, and brush competition hazards resulting from overstory manipulation are variable. Usually only the more productive or more protected sites in the FEID phase offer fair timber management opportunities.

Deer use is light to moderate. Overstory manipulation appears to increase use, particularly where brush development occurs. Sheep and cattle utilize this habitat type for forage; PIPO/FEID is one of the most important forest habitat types in the Uinta Mountains for livestock.

Other studies.—PIPO/FEID h.t.'s similar to the FEID phase were described for Montana (Pfister and others 1977), eastern Washington, northern Idaho (Daubenmire and Daubenmire 1968), central Idaho (Steele and others 1981), and north-central Wyoming (Hoffman and Alexander 1976). The ARPA and ARTR phases have not been previously reported in those areas. Dealy (1971), however, described a seral *Pinus ponderosa/Arctostaphylos patula/Festuca idahoensis* community that occupies residual soils within the *Abies concolor* zone of south-central Oregon. The ARPA and ARTR phases should be considered regional variants that are not closely related to PIPO/FEID h.t. of the Rocky Mountains.

Pseudotsuga menziesii Series

Distribution.—Throughout much of northwestern Utah and adjacent Idaho, *Pseudotsuga* is the indicated climax of low to moderate elevations. This broad elevational belt ranges from below 5,000 feet (1 525 m) to 8,000 feet (2 440 m), and locally up to about 8,800 feet (2 680 m). In general, the lower exposures are very protected, steep, northerly canyon slopes. Some of these locally reflect lower treeline, if woodland species are excluded. *Pseudotsuga* grows on southerly or westerly exposures at the highest elevations.

Nearby warmer or drier exposures at low to moderate elevations are occupied by *Acer grandidentatum* or occasionally *Juniperus* woodlands. Shrub-dominated communities (all of which are briefly described by Ream 1964) may border *Pseudotsuga* elsewhere. The *Pinus flexilis* series may be adjacent, but only at moderate elevations. The *Abies lasiocarpa* series occupies adjacent, cooler or more mesic sites and also bounds the series at higher elevations. South of Ogden, Utah, *Abies concolor* largely replaces *Pseudotsuga* as the indicated climax in this elevational zone.

In the Uinta Mountains, the *Pseudotsuga* series has a more limited distribution, largely because it is somewhat restricted to the various (but chiefly calcareous-dominated) sedimentary substrates that flank the central quartzite core. Thus, it is very local except in the eastern and southern areas. There, it occupies moderate to steep slopes between 7,000 and 9,600 feet (2 135 and 2 925 m) elevation. With the exception of local occurrences in the northeastern area, these sites do not represent lower treeline.

This series is bordered on drier or lower sites by the *Pinus contorta* and occasionally the *Pinus ponderosa* series or, in the northeastern area, shrub communities. More moist exposures contain the *Picea pungens* series or at higher elevations, the *Abies lasiocarpa* series.

Vegetation.—Stands vary from very open on exposed sites, as scattered trees or groups, to rather dense on more moderate exposures. Several seral associates are present in the series (appendix B), but *Pseudotsuga* is usually the principal pioneer species as well as the indicated climax. At lower elevations in the northwestern region, *Acer grandidentatum* is also very important, as is *Pinus ponderosa* in the Uintas. *Populus tremuloides* and *Pinus contorta* are important seral constituents at higher elevations, although the latter is largely absent from northwestern Utah. *Pseudotsuga* is clearly the most shade tolerant of the conifer associates; in the absence of major disturbance, such as an intense surface fire, it is conceivably the only conifer within the zone that can successfully reproduce in the shade of the overstory canopy.

Although variable, the undergrowth is predominantly brushy, especially in the low elevation habitat types. Occasionally, however, undergrowth has a chiefly herbaceous nature, as in the case of the OSCH phase of the PSME/OSCH h.t. Undergrowth is depauperate only in

stands of the PSME/BERE h.t., BERE phase that have dense canopies.

Soils/climate.—Even though a variety of parent materials are associated with this series (appendix D-1), most are wholly or at least weakly calcareous, or include shale. The *Pseudotsuga* series is infrequently associated with the Wasatch conglomerate; where this formation occurs within the environmental compass of climax *Pseudotsuga*, persistent *Populus tremuloides* communities are frequently found.

Normally the soils, derived from moderately deep colluvium or shallow, jointed bedrock, are gravelly and well drained. Surface soil textures encompass all textural classes, but most are loamy or finer. Considerable rock is frequently exposed. Bare soil is generally absent unless sites are intensely utilized by livestock. Litter varies from intermittently shallow to uniformly deep.

Climatic data from the Utah State University weather station, located at the mouth of Logan Canyon about 300 feet (100 m) in altitude below the occurrence of the *Pseudotsuga* series, are shown in appendix D-2.

Fire history.—In the northwestern region, all but the most inaccessible stands are second-growth (about 90 to 120 years old), having been cut and subsequently burned during the settlement of the surrounding valley areas (Bird 1964). The natural fire frequency, therefore, is largely conjecture. Most stands in the Uinta Mountains, however, are old-growth and appear to be of fire origin. Undoubtedly, light surface fires have been frequent historically, as indicated by multiple fire scars on older trees and by numerous, layered charcoal fragments that are typically encountered in most surface soils and duff. In both regions, the effect on vegetation in general and undergrowth in particular is probably only transitory, most likely producing a flush of shrub and herbaceous growth (Lyon 1971; Lyon and Stickney 1976).

Productivity/management.—Timber productivity ranges from very low to high (appendix E). Although stockability limitations are present with some habitat types or phases, productivity for lower elevation types is generally comparable to that of the more moderate portion of the *Abies lasiocarpa* series. Opportunities for timber management are generally good in the moderate part of the Uinta *Pseudotsuga* series. Parts of the PSME/BERE h.t. provide excellent timber management possibilities in the northwestern region. Several pertinent considerations are associated with regenerative activities; these are discussed for each habitat type. In general, natural regeneration is best secured with shelterwood techniques. Dwarf mistletoe (*Arceuthobium douglasii*) is very localized in northern Utah and is currently not a major problem, probably because of past logging.

Nontimber values such as watershed protection, wildlife habitat, esthetic considerations, and diverse recreational opportunities are important throughout the series. During favorable weather and snow conditions, the lower brushy habitat types provide alternate big game wintering areas to the usual *Juniperus* woodlands.

PSEUDOTSUGA MENZIESII/PHYSOCARPUS MALVACEUS H.T.(PSME/PHMA; DOUGLAS-FIR/NINEBARK)

Distribution.—PSME/PHMA is the major low-elevation habitat type in this series in northwestern Utah and adjacent Idaho. It occupies steep to very steep protected exposures, typically northwest- to northeast-facing, lower and middle slopes, between about 5,000 and 7,000 feet (1 520 to 2 130 m) elevation.

Vegetation.—*Pseudotsuga* is the indicated climax. *Acer grandidentatum* is the most common seral tree. Rarely *Pinus contorta* is a major seral component in southeastern Idaho.

Undergrowth is brushy and best characterized as consisting of several distinct structural components or layers. *Physocarpus*, typically dense, is the dominant shrub (fig. 6). This is overtopped by patchy *Amelanchier alnifolia* and several other tall shrubs that vary by phase. *Berberis repens, Pachistima myrsinites, Rosa woodsii*, and *Symphoricarpos oreophilus* constitute a lower shrub component. *Arnica cordifolia* is often the most conspicuous herbaceous species; others that occur throughout the type include *Cystopteris fragilis, Fragaria vesca, Mitella stauropetala, Smilacina racemosa*, and, locally, *Carex geyeri*. Ground moss is occasionally notable, and *Osmorhiza chilensis* is frequently abundant on toe-slope sites reflecting greater moisture and deeper soil material.

Figure 6. *Pseudotsuga menziesii/Physocarpus malvaceus* h.t. on a steep northerly exposure in Blacksmith Fork drainage east of Logan, Utah (6,300 feet [1 920 m] elevation). The dense shrub layer of *P. malvaceus* contains substantial amounts of *Pachistima myrsinites* and an herb undergrowth of primarily *Carex geyeri*.

Adjacent warmer exposures contain *Acer grandidentatum, Physocarpus, Prunus*, or *Symphoricarpos-Artemisia tridentata* shrub communities. Cooler or more rocky sites are often the PSME/BERE h.t. PRVI phase.

Soils.—Stands in northern Utah and adjacent Idaho normally occur on very stony colluvium. Parent materials are calcareous or quartziferous (appendix D). Soil surface textures are mainly loamy or finer. Within the type some surface rock is typical; bare soil is generally absent. Litter depth averages 7.5 cm overall.

Productivity/management.—Timber productivity is low to moderate (appendix E). Although productivity may be moderate, timber management opportunities are very limited because of the typical steepness of sites and difficult hardwood and brush control associated with overstory manipulation. Shelterwood techniques are often the most reliable regeneration strategy.

This habitat type is an important part of deer winter range in this area. In addition, many sites have considerable esthetic and watershed cover values. Domestic livestock use is nominal.

Other studies.—The PSME/PHMA h.t. occurs throughout the Northern Rocky Mountains. It has been described from eastern Washington, northern Idaho (Daubenmire and Daubenmire 1968), Montana (Pfister and others 1977), central Idaho (Steele and others 1983). Hoffman and Alexander (1976) and Moir and Ludwig (1979) have described a similar habitat type, PSME/*Physocarpus monogynus*, from north-central Wyoming and northern New Mexico.

Steele and others (1983) have broadly classified this habitat type in southern Idaho and western Wyoming as the PAMY phase to geographically differentiate it from the PSME/PHMA h.t. of central Idaho.

PSEUDOTSUGA MENZIESII/ACER GLABRUM H.T. (PSME/ACGL; DOUGLAS-FIR/MOUNTAIN MAPLE)

Distribution.—PSME/ACGL is a relatively cool and moist habitat type in this series. It occurs locally throughout northwestern Utah and adjacent Idaho at 5,800 to 7,500 feet (1 770 to 2 285 m), and infrequently in the Uinta Mountains above 7,700 feet (2 350 m) elevation. It is generally associated with the cold air drainage features common to middle and lower slopes, such as ravines or stream bottoms. These slopes are usually very steep and north- to northeast-facing.

Adjacent habitat types include the relatively warmer PSME/OSCH and PSME/PHMA h.t.'s or the drier PSME/BERE h.t. Cooler bordering sites are most often ABLA/ACGL or ABLA/ACRU h.t.'s.

Vegetation.—*Pseudotsuga* is the indicated climax and most often is the major component of seral stands. Many minor seral species occur locally (appendix B), of which *Populus tremuloides* is the most common.

Undergrowth generally has several canopy components (fig. 7). The prominent high-shrub layer typically includes *Acer glabrum, Amelanchier alnifolia*, and *Prunus virginiana*, whereas *Berberis repens, Pachistima myrsinites*, and *Symphoricarpos oreophilus* comprise a lower, less conspicuous one. Herbaceous vegetation is diverse: the most common species are *Arnica cordifolia, Disporum trachycarpum, Fragaria vesca, Mitella stauropetala, Osmorhiza* spp., and *Smilacina racemosa*. In addition, *Carex geyeri* and *Calamagrostis rubescens* may be locally abundant.

Soils.—These stands are associated with mixed calcareous or quartziferous substrates (appendix D). Soil surface textures range from sandy loam to clayey. Considerable amounts of coarse fragments are often present in the profile. Some stands have a great amount of surface rock but exposed soil is generally absent. The litter averages 2.2 inches (5.5 cm) in depth, with an observed maximum of 8.7 inches (22 cm).

Productivity/management—Timber productivity is low to high (appendix E). This habitat type includes some of the highest observed values in the series, although the average site index is slightly lower than that of the PSME/PHMA and PSME/OSCH h.t.'s. Management opporunities for timber, however, are generally restricted in northern Utah by steepness of slope and limited extent of the habitat type. Where opportunities exist, the shelterwood method should provide some control over subsequent brush development. Scarification may also be necessary where rhizomatous graminoids are present.

Use of this habitat type by domestic livestock is very low. Deer use is moderate.

Other studies.—We consider this habitat type to correspond to the PAMY phase as described by Steele and others (1983) for the PSME/ACGL h.t. of eastern Idaho and western Wyoming. As such, this phase serves as a geographical distinction from the ACGL and SYOR phases of central Idaho (Steele and others 1981).

Figure 7. *Pseudotsuga menziesii/Acer glabrum* h.t. on a moderately steep northeastern exposure (7,000 feet [2 130 m] elevation) in the Raft River Mountains. The moderately dense shrub undergrowth of *A. glabrum, Amelanchier alnifolia, Pachistima myrisnites*, and *Ribes viscosissimum* is underlain by substantial cover of *Calamagrostis rubescens* and *Arnica cordifolia*.

PSEUDOTSUGA MENZIESII/OSMORHIZA CHILENSIS H.T.(PSME/OSCH; DOUGLAS-FIR/MOUNTAIN SWEETROOT)

Distribution.—This relatively warm, moist habitat type occurs locally in northwestern Utah and adjacent Idaho, but principally in the northern Wasatch Range (fig. 8). It usually occupies moderate to steep lower to middle

Figure 8. *Pseudotsuga menziesii/Osmorhiza chilensis* h.t. on a moderate northerly exposure at the north end of the Bear River Range, Wasatch-Cache National Forest at an elevation of 6,800 feet (2 070 m). The undergrowth consists primarily of the herbaceous *Arnica cordifolia* and *Thalictrum fendleri*.

slopes between 5,400 and 7,400 feet (1 646 and 2 256 m) with northwest- to northeast-facing exposures. Sites are normally fairly protected.

Vegetation.—*Pseudotsuga* is the indicated climax. *Acer grandidentatum* and *Populus tremuloides* are locally major seral associates. *Pinus contorta* is occasionally a seral associate in Idaho.

Undergrowth is diverse. Common species include the indicator *Osmorhiza chilensis* (or *O. depauperata* at higher elevations) and *Amelanchier alnifolia, Berberis repens, Symphoricarpos oreophilus, Smilacina racemosa*, and *Thalictrum fendleri*. Sites that receive regular livestock use normally have an abundance of weedy species. Interestingly, *Circea alpina* was only encountered in the *Pseudotsuga* series in this habitat type.

Acer, Prunus, and other shrub communities occupy nearby warmer and drier sites. Drier forested sites, typically upslope, are normally the PSME/BERE h.t.

Soils.—This habitat type occur almost exclusively on colluvium. Various parent materials are represented (appendix D). Subsurface coarse fragments are usually present, and surface soil textures range from loamy to clayey. Surface rock is generally absent. Bare soil is occasionally present. The average litter depth of the habitat type is 2.4 inches (6.2 cm).

Productivity/management.—Timber productivity is moderate to high (appendix E). This type has the highest overall sampled site index, productivity, and basal area increment and development of the northern Utah *Pseudotsuga* h.t.'s. These values appreciably reflect the overall moderate environment of the type and in particular the moistness of the colluvial soils. Opportunities for intensive timber management, however, are limited because of the scarcity of the habitat type.

A shelterwood best reflects the *Pseudotsuga* regeneration patterns observed in mature stands. Also, this method provides some additional site protection from potential hardwood and brush development. In this series, pocket gopher activity appears to be greatest in this habitat type, perhaps because of the typical lushness of herbaceous vegetation and conducive soil factors, as well as the close proximity of meadow areas.

Both deer and domestic livestock utilize the habitat type for cover and limited forage.

Other studies.—This type has also been described in central Idaho (Steele and others 1981), and eastern Idaho (Steele and others 1983).

PSEUDOTSUGA MENZIESII/CALAMAGROSTIS RUBESCENS H.T.(PSME/CARU; DOUGLAS-FIR/PINEGRASS)

Distribution.—We sampled this habitat type on a steep cool-dry exposure at 6,440 feet (1 963 m) elevation in the extreme northwestern extension of the Wasatch Range near Malad, Idaho. Isolated occurrences are to be expected in northwestern Utah and the westernmost Uintas, which would probably represent the southernmost extent of the habitat type. The PSME/CARU h.t. is apparently absent from the eastern Uinta Mountains because *Abies lasiocarpa* is the most probable indicated climax of sites having a dense *Calamagrostis* undergrowth component.

The PSME/CARU h.t. in southeastern Idaho and adjacent Wyoming is recognized as the PAMY phase and is described in detail by Steele and others (1983).

Vegetation.—*Pseudotsuga* is the indicated climax. It is the only conifer present in the stand. Elsewhere in Idaho, *Pinus contorta* is an important seral species. *Calamagrostis rubescens* conspicuously dominates the undergrowth. Small amounts of *Pachistima myrsinites, Prunus virginiana*, and *Symphoricarpos oreophilus* are present, with small amounts of various herbs.

Soils.—Our example of this habitat type has quartziferous and calcareous parent materials and a clayey surface soil. Surface rock and bare soil are absent. The litter is 2.0 inches (5.0 cm).

Productivity/management.—Steele and others (1983) report timber productivity to be low to moderate. Our stand has moderate productivity and an above average site index.

Other studies.—Similar habitat types are found throughout the Northern Rocky Mountains. In addition to eastern Idaho and western Wyoming, it has been described from central Idaho (Steele and others 1981), Montana (Pfister and others 1977), northern Idaho, eastern Washington (Daubenmire and Daubenmire 1968), Alberta (Ogilvie 1962), British Columbia (McLean 1970), and eastern Oregon (Hall 1973).

PSEUDOTSUGA MENZIESII/CERCOCARPUS LEDIFOLIUS H.T.(PSME/CELE; DOUGLAS-FIR/CURLLEAF MOUNTAIN-MAHOGANY)

Distribution.—This minor habitat type is found principally in the Wasatch Range in areas adjacent to the Utah-Idaho border. It also occurs in the Stansbury Mountains. PSME/CELE occupies a variety of dry, very exposed slopes from about 6,300 feet (1 920 m) elevation on northerly aspects, to 8,000 feet (2 440 m) on southerly exposures. Sites are subject to year-round winds and

intense isolation, which contribute to desiccation as well as reduced snowpack and snow retention. These factors, in conjunction with the typically shallow, rocky soils, make the environment the most severe of the *Pseudotsuga* series.

Vegetation.—*Pseudotsuga* is the indicated climax. Trees occur as scattered individuals or in groups. *Juniperus scopulorum* and *Pinus flexilis* are minor seral species. The PIFL/CELE h.t. occurs where *Pinus* rather than *Pseudotsuga* is a reproducing dominant.

Undergrowth is dominated by *Cercocarpus ledifolius*, which is very persistent in old-growth stands (fig. 9).[2] Many other shrubs are present, including *Amelanchier, Artemisia tridentata, Berberis repens, Prunus virginiana, Symphoricarpos oreophilus*, and occasionally *Ceanothus velutinus*. The herbaceous component is diverse, the most common species being *Achillea millefolium, Balsamorhiza sagittata, Crepis acuminata, Stellaria jamesiana, Agropyron spicatum, A. trachycaulum*, and *Leucopoa kingii*. These species reflect often the adjacent mixed-shrub, *Cercocarpus*, or grass communities where moisture stress inhibits tree growth. The PSME/BERE h.t. often occurs nearby on more protected sites.

Soils.—This type occurs primarily on calcareous parent materails (appendix D). Soils are shallow and very gravelly, and have the broadest range of surface textures in the series. Surface rock and bare soil range from absent to considerable. The average litter depth is 1.7 inches (4.2 cm).

Figure 9. *Pseudotsuga menziesii/Cercocarpus ledifolius* h.t. in the northern portion of the Wasatch Range on a steep northwesterly exposure at 6,300 feet (1 920 m) elevation. The predominently shrubby undergrowth is dominated by *C. ledifolius, Symphoricarpos oreophilus*, and *Amelanchier alnifolia*.

[2]Low elevation stands of the PSME/BERE h.t. in early to mid-successional stages occasionally have abundant *Cercocarpus*. In such circumstances, this species is considered seral.

Productivity/management.—Timber productivity is very low (appendix E) and stockability limitations are present. Some sites which are adjacent to the PSME/BERE h.t., however, have moderate productivity.

Although forage is generally good, many stands are inaccessible to livestock because of the denseness of *Cercocarpus* and other shrubs. Other values, particularly deer habitat and watershed cover, are of much greater importance.

Other studies.—The PSME/CELE habitat type was recognized in central Idaho (Steele and others 1981) and eastern Idaho and western Wyoming (Steele and others 1983).

PSEUDOTSUGA MENZIESII/BERBERIS REPENS H.T.(PSME/BERE; DOUGLAS-FIR/OREGONGRAPE)

Distribution.—With four phases, this is the most common habitat type in the *Pseudotsuga* series. It is represented by 66 sample stands. Table 4 summarizes the range of environment conditions by phase and geographic region.

In northwestern Utah and adjacent Idaho, PSME/BERE occupies relatively warm and dry forested sites through a 3,500-foot (1 067-m) range of elevation, from 5,400 to nearly 9,000 feet (1 067 to 2 743 m). The type occurs on all exposures at higher elevations, but only on northerly exposures at low elevations. It commonly occupies moderate to very steep middle to upper slopes.

This habitat type is generally more mesic in the Uinta Mountains than elsewhere in Utah. In the Uintas it occurs on all aspects and elevations from 7,200 to 9,600 feet (2 195 to 2 926 m). Its presence on slopes and lower elevation exposures here are similar to those of northwestern Utah.

Vegetation.—*Pseudotsuga* is the indicated climax. Many seral species are associated with this habitat type (appendix B), but in many stands *Pseudotsuga* is the only conifer present, particularly in northwestern Utah. There, *Acer grandidentatum* is the most notable major seral species of low elevation stands. In the Uinta Mountains, *Pinus contorta, P. ponderosa*, and *Populus tremuloides* are the major seral associates, each having local distributions.

Undergrowth generally is diverse, varying from very brushy to depauperate (fig. 10). These conditions are reflected by the phases. Many species are common only to certain phases or to parts of phases (appendix C), corresponding to an altitudinal gradient in general. In addition to the joint indicators *Berberis repens* and *Pachistima myrsinites*, the species *Amelanchier alnifolia, Symphoricarpos oreophilus*, and *Poa nervosa* occur throughout the type.

***Carex geyeri* (CAGE) phase.**—This phase occurs infrequently in northwestern Utah and adjacent Idaho. The normally steep exposures appear to include the same temperature regime as sites without *C. geyeri* but probably have different edaphic conditions. In addition to the typal species, undergrowth notably includes *Salix scouleriana, Aster engelmannii*, and *Thalictrum fendleri*.

The CAGE phase is more common, but local, in the Uinta Mountains. It apparently is restricted to sand-

Table 4.—Distribution of PSME/BERE h.t. in northern Utah by phase and region

Phase	Northwestern Utah[1]		Uinta Mountains	
	Elevation range	Exposure	Elevation range	Exposure
	Feet (m)		*Feet (m)*	
CAGE	6,600-8,100 (2 012-2 469)	N-NE	7,500-9,200 (2 286-2 804)	NE,S
JUCO	—		8,100-9,600 (2 469-2 926)	All
SYOR	6,000-8,800 (1 829-2 682)	All	8,300-9,200 (2 530-2 804)	All
BERE	5,400-8,000 (1 646-2 438)	NW-NE	7,300-9,600 (2 225-2 926)	All

[1]Includes adjacent Idaho.

Figure 10. *Pseudotsuga menziesii/Berberis repens* h.t. on a steep northwest exposure (6,400 feet [1 950 m] elevation) in the Bear River Range, Wasatch-Cache National Forest. The sparse undergrowth consists of a mix of low shrubs and herbs.

stone and quartzite substrates. Exposures are warm and dry, and moderate to very steep. Undergrowth is usually characterized by abundant coverage of *Carex*. In addition to the species that occur throughout the type, *Juniperus communis* is common, and *Arctostaphylos uva-ursi* and *Astragalus miser* are locally abundant. Where *Pinus ponderosa* is a major seral associate, nearby warmer and drier sites are the PIPO/CAGE h.t.; elsewhere adjacent habitat types are variable.

***Juniperus communis* (JUCO) phase.**—This cool, dry phase is apparently restricted to the central and eastern Uinta Mountains where it is associated with the sedimentary formations that flank the central quartzite core of the range. (It is also to be expected on the Uinta National Forest portion of the southwestern Uinta Mountains, and possibly at the higher elevations of the Wasatch Range where *Juniperus* occurs very infrequently.) In the northeast this phase frequently occupies all exposures in a narrow altitudinal band at the upper elevations of the sedimentary formations; on the other hand, exposures are mostly protected in the southern area. Topography is steep to very steep.

Pinus contorta and *Populus tremuloides* are important seral associates in southern areas, but *Pseudotsuga* is usually the only tree in northeastern stands. Undergrowth is typically brushy, with *Juniperus* as the dominant species. The herbaceous component is normally depauperate, having *Galium boreale* and *Carex rossii* as the most common species. On some sites, however, *Astragalus miser* is conspicuous.

Nearby warmer and drier exposures are the PICO/BERE c.t. principally in the southern area and PSME/SYOR h.t., which is usually lower in the northeastern areas. The slightly more mesic PIPU/BERE h.t. is sometimes adjacent in the southeastern area. In the northeast nearby cooler or more mesic sites are the BERE phase or the ABLA/BERE h.t.

***Symphoricarpos oreophilus* (SYOR) phase.**—This phase is common in the northern Wasatch Range of Utah. In the Uinta Mountains, where it is infrequent, sites reflect exposures intermediate to those of the PSME/SYOR h.t. and the JUCO and BERE phases of the PSME/BERE h.t.

The SYOR phase in northwestern Utah occupies some of the warmest and driest forested sites. These are very steep at lower 6,000-foot (1 829-m) elevations. Between 7,000 and 9,000 feet (2 134 to 2 743 m), the typical midslope to ridgetop topography is moderate to very steep.

Stands are either isolated or are open, with scattered trees that never achieve complete canopy closure; stands with dense canopies are usually in the BERE phase. *Pseudotsuga* is the dominant conifer. *Abies lasiocarpa* is accidental. Undergrowth is usually brushy and dominated by *Symphoricarpos* and *Leucopoa kingii*. Normally, lower elevation sites have abundant cover of *Arnica cordifolia* as well.

Adjacent, more mesic exposures are the BERE phase of this habitat type or the ABLA/BERE h.t. Drier sites are *Symphoricarpos*-dominated communities.

***Berberis repens* (BERE) phase.**—This is the commonest phase in the habitat type. In northwestern Utah and adjacent Idaho, elevations for the habitat type range from 5,400 to 7,500 feet (1 646 to 2 286 m), but most sites occur above 6,000 feet (1 829 m). Topography is variable, ranging from moderate to very steep. Exposures are relatively warm and dry but are normally more moderate than those of the other phases.

Pseudotsuga is usually the only tree present, but some lower stands have, in addition, a nominal coverage of *Juniperus scopulorum.* Undergrowth is variable. Sites at the lower elevations have many species in common with the PSME/PHMA h.t. Higher sites are normally depauperate except for the typal shrubs.

Nearby habitat types at lower elevations include the more mesic PSME/PHMA, the cool-moist PSME/ACGL, or the very warm and dry SYOR phase. At higher elevations adjacent habitat types are the warm-moist PSME/OSCH, or the cool-moist PSME/ACGL or ABLA/ACGL h.t.'s; cool and dry sites are ABLA/BERE; warmer sites are the SYOR phase (particularly near forest fringes); and very warm and dry sites are frequently PSME/CELE h.t. or nonforest vegetation.

In the Uinta Mountains, the BERE phase is common only in the northeastern area. The moderate to very steep exposures are normally the most mesic of the Uinta *Pseudotsuga* series. Substrates include sedimentary materials, chiefly limestone, and occasionally quartzite.

Pinus contorta is a major seral associate of most stands. Undergrowth is typically depauperate. *Berberis* is often the most abundant species, with small coverages of *Juniperus communis* and the other typal species being additionally present.

In the Uinta Mountains, adjacent sites include the warmer PICO/BERE c.t., the higher cool-dry JUCO phase, or the cooler and more moist ABLA/BERE h.t. Nonforest communities frequently abut this phase.

Soils.—Our stands occur on sedimentary and quartzite substrates (appendix D). Surface soil textures, which range from sandy loam to clayey, reflect this variety of parent materials. Soils are typically shallow and most have considerable coarse fragments. Overall, the soils of stands in the Uinta Mountains are coarser textured. Surface rock is variable but bare soil is generally absent. The average duff depth for the type is 4.5 cm; the range of the average phase values is 3.3 cm (JUCO) to 5.5 cm (BERE).

Productivity/management.—Productivity is very low to moderate (appendix E). Overall, productivity values for this habitat type are the lowest for the types having management possibilities in this series. The highest productivity for the type occurs in the CAGE phase. The SYOR and JUCO phases have the lowest because of low site index in combination with stockability limitations. The BERE phase has the greatest range of productivity values and the highest site index (64 feet) of the PSME/BERE stands sampled. Overall, the average productivity and site index of Uinta Mountain stands is lower than that of the northwestern stands. It is also noteworthy that this habitat type has the vast majority of the old-growth stands in the *Pseudotsuga* series.

Opportunities for timber management are generally good for all phases except the SYOR, wherever slope or other factors are not restrictive. *Pseudotsuga* is the only conifer available for management in northwestern Utah. In the Uinta Mountains, *Pinus contorta* or *P. ponderosa* may present additional opportunities in some stands. With overstory manipulation, many sites in both areas are subject to excessive brush competition and insolation. This suggests the use of a shelterwood for securing natural regeneration. Small clearcuts with planting also appear to be satisfactory on the better, more moist sites. Where *Carex geyeri* is present, scarification may be necessary.

Lower elevation sites in northwestern Utah are an important part of deer winter range. Other sites appear to receive variable summer use by deer and elk, mainly for cover. Domestic livestock may make heavy use of this habitat type for shade when grazing areas are nearby.

Other studies.—This habitat type was described for central Idaho by Steele and others (1981). The type and phases are recognized as occurring throughout southern Idaho as well as in scattered locations of western Wyoming (Steele and others 1983). The PSME/BERE h.t. has also been described from the Bighorn Mountains of Wyoming by Hoffman and Alexander (1976).

PSEUDOTSUGA MENZIESII/SYMPHORICARPOS OREOPHILUS H.T.(PSME/SYOR; DOUGLAS-FIR/MOUNTAIN SNOWBERRY)

Distribution.—Although this habitat type occurs locally throughout the Uintas, it is common only in the northeastern area. It is rarely encountered in northwestern Utah and adjacent Idaho. The type occupies ridges and moderate to steep middle and upper slopes. Exposures are relatively warm and dry; it is found at elevations ranging from 7,000 to 9,600 feet (2 134 to 2 926 m).

Vegetation.—*Pseudotsuga* is the indicated climax, and the undergrowth is characterized by *Symphoricarpos.* Several seral species are locally present (appendix B), of which *Populus tremuloides* and, at lower elevations, *Pinus ponderosa* are the most notable. In general, stands are the most open of the Uinta *Pseudotsuga* series.

Undergrowth is variable but normally brushy, being dominated by *Symphoricarpos* and, on some sites, *Juniperus communis* or *Artemisia tridentata vaseyana.* The herbaceous component is typically depauperate with *Carex rossii* and *Leucopoa kingii* as the most common species.

In many locations this type borders lower, warmer, and drier *Symphoricarpos-Artemisia* communities. Adjacent cooler sites are the PSME/BERE h.t., BERE phase, or wherever *Juniperus* is a major undergrowth component, the JUCO phase.

Soils.—Our stands have a variety of substrates (appendix D). Soils are gravelly, and surface textures range from sandy loam to clayey. The type has moderate surface rock but little bare soil. The average litter depth is 4.4 cm.

Productivity/management.—Productivity is very low to low (appendix E) because of low site index in combination with stockability limitations. Management oppor-

tunities are limited to the protected, better sites. Regeneration strategies should follow natural patterns, like shelterwood; larger clearcuts will be difficult to regenerate because of brush competition and excessive insolation and droughty conditions.

Deer use this type moderately and mainly for cover. Domestic livestock use is principally for shade, and is high wherever grazing areas are nearby. This habitat type is also important watershed cover at higher elevations.

Other studies.—The PSME/SYOR habitat type has been described from southwestern Montana (Pfister and others 1977), central Idaho (Steele and others 1981), and eastern Idaho and western Wyoming (Steele and others 1983). Reed (1976) recognized the PSME/SYOR habitat type as a much broader concept in the Wind River Range, Wyo.

Where *Juniperus* is a major undergrowth component, the type is somewhat similar to the PSME/JUCO habitat types of the above authors (excluding Reed).

Picea pungens Series

Distribution.—Stands with *Picea pungens* as a component are locally common throughout the Uinta Mountains. Such stands also occur occasionally in the canyons near and to the south of Salt Lake City. *Picea pungens* is more abundant and important throughout southern Utah.

Stands in northern Utah where *P. pungens* is the indicated climax occur mainly in the southeastern and northern Uinta Mountains at elevations between about 7,800 and 8,800 feet (2 375 and 2 680 m). Sites range from warm, dry, steep, southerly slopes or ridgetops to relatively mesic canyonsides to very wet streamsides. This series probably reflects a topographic and edaphic climax, as suggested by Pfister (1972). These three site conditions for *P. pungens* also occur in the southwest (Moir and Ludwig 1979; Pearson 1931).

In the southeastern Uinta Mountains the series is bordered by the warmer and drier *Juniperus* woodland, *Populus tremuloides* series, or shrub communities which are dominated by *Artemisia* spp. and *Symphoricarpos oreophilus*, with a variety of herbaceous species (Cronquist and others 1972). The *Pinus contorta* series usually borders it in the northern Uintas.

Stands where *P. pungens* is a major dominant also occur on the northern slope of the Uinta Mountains on private lands, which were not sampled. Most of these stands occupy streamside terraces or other related landforms, and are usually at the lowest elevations at which conifers are encountered. Undergrowth of several observed wet sites was dominated by species of *Salix*, *Carex*, and *Equisetum*. In contrast, near Robertson, Wyo., a relatively warm site having deep clayey alluvial sediments and very dry surface soils was observed on the Blacks Fork River. Undergrowth was dominated by *Arctostaphylos uva-ursi*, *Juniperus communis*, and *Potentilla fructicosa*.

Of special consideration are the streamside sites within the montane zone throughout northern Utah that have *P. pungens* as a major climax associate. These sites are uncommon and were not sampled but include great variation in undergrowth. Sites such as terraces where *Equisetum arvense* is a major component are included in the *Picea engelmannii*/EQAR h.t., after Steele and others' (1983) treatment for this situation in eastern Idaho and western Wyoming. Other riparian sites are unclassified.

Vegetation.—In the Uinta Mountains, it appears that *Picea pungens* has an intermediate shade tolerance, as suggested by Daniel and others (1979). Stand structure analysis shows that it is significantly less tolerant than *Abies lasiocarpa* and *Picea engelmannii*. We believe that in this area it is slightly more tolerant than *Pseudotsuga*, although a reverse relationship is indicated in eastern Arizona by Jones (1974). Other common associates (appendix B) are clearly less tolerant.

Perhaps of more significance, however, when considering this species' competitive relationship with *Pseudotsuga*, is its apparent adaptation to warmer temperature regimes, especially very dry sites with calcareous substrates. In this sense, *P. pungens* usually has a distinct competitive advantage over *Pseudotsuga*. When cooler and moister sites are considered, or those that have weakly calcareous or noncalcareous substrates such as sandstone, this relationship is sometimes less discernible and care must be taken to place a particularly questionable stand in the appropriate series. In general, the more productive of these sites, as measured by site index, are usually the *P. pungens* series. Often, however, the tolerance relationship is directly apparent. In some stands that exceed 300 years of age for example, stand structure is somewhat similar to that of old-growth *Picea engelmannii-Abies lasiocarpa* stands; *Pseudotsuga* is dominant in the upper canopy and *P. pungens* is reproducing in the lower.

Excluding wet sites, undergrowth reflects a bimodal range of environmental conditions. Warm-dry extremes are characterized by *Agropyron spicatum* and a host of other species. More moist sites normally have brushy undergrowth dominated by *Berberis repens, Juniperus communis*, or *Pachistima myrsinites; Arnica cordifolia, Galium boreale*, and *Thalictrum fendleri* are present also.

Soils.—A variety of parent materials are associated with this series (appendix D). These are principally limestone or mixtures of various sedimentary materials of which many are weakly calcareous (Kinney 1955). Quartzite is only common as a predominant parent material in the northern area where it is usually associated with glacial or alluvial depositions.

Soils are gravelly. Surface textures range from loamy to clayey. Exposed bedrock, surface rock, and bare soil are most abundant, with the drier sites in the series where litter accumulation is also least. Average litter depth for the series is 0.9 inches (2.4 cm).

Fire history.—Charcoal fragments are present mainly in the more mesic part of the series, but an overall past fire history and its influence on vegetation is not clear. Light surface fires probably have had little long-term effect on undergrowth. Nevertheless, this type of fire may have greatly influenced overstory composition by destroying *Picea pungens*. If such is the case, then larger individuals of *Pseudotsuga* would survive, and seral stands would be maintained.

Productivity/management.—Timber productivity is low to moderate (appendix E). *Picea pungens* is the most productive species but it is presently not extensively utilized; *Pseudotsuga* and *Pinus contorta* are the principal management species.

Deer use for cover and browse is moderate and livestock use is locally important where adjacent forage is also available. This series also provides watershed protection.

Other studies.—*Picea pungens* habitats have been described throughout the central and southern Rocky Mountains, from Utah (Kerr and Henderson 1979; Pfister 1972; Ream 1964), Arizona and New Mexico (Moir and Ludwig 1979), New Mexico and Colorado (Peet 1978), and western Wyoming (Steele and others 1983).

PICEA PUNGENS/AGROPYRON SPICATUM H.T. (PIPU/AGSP; BLUE SPRUCE/BLUEBUNCH WHEATGRASS)

Distribution.—This warm, dry habitat type is locally common in the southeastern Uinta Mountains. It occupies moderate to steep slopes or ridgetops between 7,800 and 8,800 feet (2 375 and 2 680 m) elevation. Exposures are overall southerly, ranging from east- to west-facing.

Vegetation.—*Picea pungens* is the indicated climax. *Abies lasiocarpa* is accidental. *Pseudotsuga* is a major seral component, as are *Pinus ponderosa* and *Populus tremuloides* in local situations. *Juniperus scopulorum* and *Pinus flexilis* are minor seral associates also having local distributions. Stands are open and rarely achieve complete canopy closure.

Undergrowth is variable, ranging from sparse to brushy. It reflects the xeric nature of this habitat type as exemplified by *Agropyron spicatum, Arenaria congesta, Linum kingii*, and *Oryzopsis hymenoides*. Dominant shrubs are *Berberis repens, Juniperus communis, Pachistima myrsinites*, and *Symphoricarpos oreophilus*. *Carex rossii* is also common. The use of *A. spicatum* as an indicator species does not imply an overall grassland physiognomy.

Warmer and drier sites are *Juniperus* woodland or nonforest communities. Adjacent, more mesic habitat types include PIPU/BERE, PSME/BERE, and ABLA/BERE.

Soils.—The soils of our stands are associated exclusively with calcareous substrates. Soils are very gravelly. Surface textures range from gravelly loams to gravelly clays. Surface rock is often considerable (occasionally including exposed bedrock) and some bare soil is present. Litter accumulation is usually intermittent, averaging 0.4 inches (1.0 cm) in depth. Erosion is often very noticeable.

Productivity/management.—Watershed cover is the most important management consideration. Deer and livestock use may be important in some situations.

Although *Picea* and *Pseudotsuga* site-index values are moderate, timber productivity is very low to low because of stockability limitations (appendix E).

Erosion hazards are present throughout much of the habitat type.

Other studies.—PIPU/AGSP habitat type has not been previously mentioned in other studies.

PICEA PUNGENS/BERBERIS REPENS H.T. (PIPU/BERE; BLUE SPRUCE/OREGONGRAPE)

Distribution.—PIPU/BERE, the more moderate habitat type of the series, occurs locally in the southeastern Uinta Mountains. It is also infrequently encountered in the northern area of this range. This habitat type occupies protected exposures at elevations of 8,000 to 8,800 feet (2 440 to 2 680 m). Slopes range from gentle to very steep.

Vegetation.—*Picea pungens* is the indicated climax. When present, *Pseudotsuga* is usually a persistent seral species. *Populus tremuloides* and *Pinus contorta* are other major seral associates.

Undergrowth is typically shrubby. In addition to the joint indicator species *Berberis* and *Juniperus communis*, normally present are *Acer glabrum, Pachistima myrsinites, Rosa* spp., and *Symphoricarpos oreophilus*. Especially noteworthy is the presence of *Ceanothus velutinus* and *Shepherdia canadensis*, which suggest the incidence of fire. Although diverse, the herbaceous component is generally depauperate, except when *Astragalus miser* or *Carex geyeri* are abundant. The most common herbs include *Anemone multifida, Arnica cordifolia, Galium boreale, Thalictrum fendleri*, and *Carex rossii*.

In the southeastern area, drier sites are nonforest communities or the POTR/CAGE or PIPU/AGSP h.t.'s. Normally the PICO/BERE c.t. is adjacent in the northern area. Nearby cooler habitat types are PSME/BERE or ABLA/BERE.

Soils.—The PIPU/BERE h.t. is associated with a greater diversity of dominant parent materials than PIPU/AGSP (appendix D). These include quartzite, limestone, and other weakly calcareous or noncalcareous sedimentary rocks. Surface textures range from sandy loam to clayey, and most soils are gravelly. Normally little surface rock and bare soil are present. The average litter depth is 1.3 inches (3.4 cm).

Productivity/management.—Timber productivity is low to moderate (appendix E). The site index values of *Picea pungens* have little variability. Although only two of the sampled *Pseudotsuga* trees were acceptable for site-index determination, the *Pseudotsuga* site index appears to be higher in this type than in the PIPU/AGSP h.t.

Small clearcuts and shelterwood cuts appear to be acceptable for regeneration of *Picea* and *Pseudotsuga*, respectively.

Deer and elk use the type moderately for cover. Only local livestock use occurs.

Other studies.—This habitat type was first noted in Utah by Pfister (1972), and subsequently by Kerr and Henderson (1979). Moir and Ludwig (1979) have described a similar habitat type (PIPU-PSME h.t., JUCO phase) from northern New Mexico.

Abies concolor Series

Distribution/climate.—Within the northern Utah study area, the *Abies concolor* series occurs throughout the higher mountain ranges of the northwestern region, roughly south of the vicinity of Ogden, Utah (latitude 41°15'). It is also found locally in the southwestern to westernmost Uinta Mountains. The series increases in

importance through southern Utah. In general, it occupies most all montane forest sites between the elevations of about 5,000 feet (1 525 m), lower timberline, and 8,000 feet (2 440 m). The series is strikingly similar in most all respects to the *Pseudotsuga menziesii* series.

North of 41°51' latitude, *Abies concolor* has an increasingly sporadic occurrence; its northernmost Rocky Mountain location is in Cottonwood Creek east of Logan, Utah. Within this tension zone, *Pseudotsuga menziesii* appears to replace *A. concolor* as the indicated climax of montane forest sites. Here, a combination of two factors seems to most strongly influence the population dynamics, and thus the distribution, of *A. concolor*.

The first factor is a critical, limiting minimum temperature that develops within this area as a result of increasing latitude. (The same limitation appears to affect *Quercus gambelii*, which also terminates in the same general area.) Based on the climatological maps provided in Brown (1960), this threshold may hypothetically correspond to a mean maximum January temperature of about 30° to 32° F (-1° to 0° C) occurring within the lower altitudinal (moisture) limits of *A. concolor*. Aside from temperature, fairly similar conditions of both substrates and precipitation occur throughout the Utah portion of the Wasatch Range, although the Great Salt Lake and Provo Lake apparently contribute to a slight increase in precipitation (appendix D-2). Thus while seedlings of *A. concolor* are commonly encountered, successful establishment would occur only during a series of the most favorable years having winters of above average temperature. While the Uinta Mountains are located south of Ogden in latitude, this same January temperature pattern occurs eastward because of the cold surrounding basins.

The second factor is that several rodents prefer to feed on the cambial tissue of *A. concolor* rather than that of *Pseudotsuga*. Hayward (1945), in a study of the Mt. Timpanogos area in the southern Wasatch Range, noted the near-complete destruction of scattered *A. concolor*, which had developed under the protective cover of *Populus tremuloides*. Given the normally episodic establishment of this species in the northernmost extent of its range, such activity could have a marked impact on population dynamics. For example, several stands of *Pseudotsuga*, as well as *Populus*, which included small populations of *A. concolor*, were located during 1972 to 1976. Typically, these included a representation of small- to medium-sized saplings. By 1977, almost all of the *A. concolor* had been destroyed by porcupines. In addition, the upper crowns of larger, widely located trees exhibited a periodic stripping of thinner bark. These feeding patterns appear to be opportunistic. In this area, many porcupines migrate from their valley and foothill wintering areas through the montane zone to their summering areas at higher elevations. Also, constant destruction of the leaders of the smaller trees by feeding mice, generally occurring at the level of snowpack accumulation, results in very "bushy," stunted individuals. Mice probably also destroy a great portion of each year's new seedlings.

Clearly, the combination of temperature constraints and rodent pressure serves to limit the success of *A. concolor* within the tension zone. With the exception of isolated sites, *Pseudotsuga* is the indicated climax within the tension zone and *A. concolor* is probably an accidental species. This relationship merits more study.

Vegetation.—*Abies concolor* usually reproduces abundantly throughout the series under conditions of dense shade, but it is an aggressive pioneer species as well. Overstory conditions are variable. On exposed, principally lower elevation sites *A. concolor* occurs either as widely spaced single trees or in scattered groups, between which brush or woodland species, chiefly *Acer grandidentatum* and *Quercus gambelii*, , are abundant.[3] *Pseudotsuga* and occasionally *Populus tremuloides* are dominant seral associates on more moderate exposures. On these sites canopies are normally more closed, often densely so. In addition, *Populus angustifolia* or *Acer negundo* is sometimes represented on sites close to streams.

Overall, undergrowth is similar to that of the *Pseudotsuga menziesii* series.

Soils.—Soils are derived from a variety of parent materials that include calcareous and noncalcareous sedimentary, complex metamorphics, granitic and quartzite rocks (appendix D). Additionally, most soils are associated with colluvium or rather shallow bedrock. A few stands occupy glacial-related features at the lower reaches of some canyons near Salt Lake City. Soils are gravelly and most are fairly well drained. All textural classes are represented in the surface soils in the series. The depth of litter and the amount of exposed rock are quite variable, but bare soil is generally absent.

Weather data from Cottonwood Weir Station, which is located lower than the series, and from Timpanogos Cave, which reflects the climate of a woodland site across-canyon from the ABCO/BERE h.t., BERE phase, are presented in appendix D-2.

Fire history.—Natural fire frequency prior to the influence of settlers is uncertain. In general, its effect on undergrowth was probably temporary and, in general, similar to that which is suggested for the *Pseudotsuga menziesii* series. Fire probably had a more significant effect on the overstory because *Abies concolor* is less fire resistant than *Pseudotsuga*. Thus, frequent light surface fires probably maintained rather open stands of large, persistent *Pseudotsuga*, and perhaps a few old *Abies* as well. In addition, *Abies* stands in local areas could be completely destroyed because their branching habit favors crowning out of surface fires.

As is the case for the *Pseudotsuga menziesii* series, many stands in the *A. concolor* series were logged and subsequently burned during the late 1800's. A review of various historical documents relating to that period indicates that *A. concolor* was just as scarce north of Ogden then as now.

Productivity/management.—Timber productivity ranges from very low to very high. The ABCO/OSCH h.t. includes some of the highest observed sample site index values of the montane zone of northwestern Utah.

[3]Such sites, however, must be capable of supporting at least 25 percent canopy cover of *Abies*, including any *Pseudotsuga*. Sites supporting less than 25 percent canopy cover of these conifers are considered as the ABCO-QUGA woodland series.

Timber management is generally limited, however, largely because other values are paramount. Timber guidelines are similar overall to those which are discussed for the *Pseudotsuga* series. Regeneration of *Abies concolor* is usually accomplished best through shelterwoods.

The series provides a multitude of nontimber benefits: deer habitat, watershed protection, and a diverse range of recreational opportunities.

Other studies.—Various *Abies concolor* habitats have been discussed for Oregon by Franklin and Dyrness (1973), who provide a summary of many studies, and for New Mexico and Colorado by Peet (1978).

Abies concolor h.t.'s have been described from central and southern Utah (Pfister 1972), and Arizona and New Mexico (Moir and Ludwig 1979). *Abies concolor/Acer glabrum* and *Abies concolor/Cercocarpus ledifolius* are unsampled habitat types that are expected to be common in the southern Wasatch Range and that possibly occur in the study area near Salt Lake City.

ABIES CONCOLOR/PHYSOCARPUS MALVACEUS H.T. (ABCO/PHMA; WHITE FIR/NINEBARK)

Distribution.—This habitat type is common in the southern Wasatch Range and Stansbury Mountains. It occupies relatively warm sites that most closely resemble those of the PSME/PHMA h.t. Slopes range from moderate to very steep.

Vegetation.—*Abies concolor* is the indicated climax. The shrubby undergrowth is dominated by typically dense *Physocarpus*. Species which occur throughout the type are *Amelanchier alnifolia, Pachistima myrsinites*, and *Prunus virginiana*. In addition, *Carex geyeri* is locally abundant. The presence of herbaceous species varies (appendix C), as does that of seral overstory associates (appendix B).

Pseudotsuga is usually a major seral associate, and stands are fairly closed. Occasionally *Acer* and *Quercus* are represented but they are persistent in the largest canopy openings only. In addition to the typal species, undergrowth includes *Symphoricarpos oreophilus, Mitella stauropetala*, and *Smilacina racemosa* as the most common species of the many that occur. Nearby drier forested sites are typically the ABLA/BERE h.t. Cooler, more mesic exposures at higher elevations are the ABLA/ACRU, ABLA/PHMA, or ABLA/ACGL h.t.'s.

Soils.—The soils of our sample stands are derived primarily from shaley quartzite (appendix D). In general, soils are gravelly with surface texture loamy to clayey. Surface rocks are usually absent. Litter depth averages 6.8 cm.

Productivity/management.—In general, timber productivity is high. This habitat type is important for deer, especially as winter range. Watershed protection and esthetic values are also high.

Other studies.—This habitat has not been previously mentioned.

ABIES CONCOLOR/OSMORHIZA CHILENSIS H.T. (ABCO/OSCH; WHITE FIR/MOUNTAIN SWEETROOT)

Distribution.—This minor, moist habitat type occurs throughout the geographical extent of the series, with the exception of the Uinta Mountains. Overall, ABCO/OSCH is fairly similar to the PSME/OSCH h.t. Exposures are northerly, steep to very steep lower and midslopes. Sites otherwise are protected and principally occupy streamsides or benches. Elevations are between about 5,400 and 7,000 feet (1 645 and 2 135 m).

Vegetation.—*Abies concolor* is the indicated climax. Normally *Pseudotsuga* is a major seral associate, and *Populus angustifolia* and *Acer negundo* are associated with streamside sites.

Undergrowth is usually brushy. Common shrubs include *Amelanchier alnifolia, Pachistima myrsinites, Prunus virginiana*, and, when the drier ABCO/PHMA h.t. is proximate, minor amounts of *Physocarpus malvaceus. Osmorhiza chilensis* is usually the most notable herbaceous species (appendix C).

Soils.—The soils of our stands are derived from a variety of substrates (appendix D). Surface textures are variable, ranging from loamy sands to clayey, and most soils are gravelly but relatively moist. Considerable surface rock but little bare soil is typically present. Litter depth averages 1.9 inches (4.8 cm).

Productivity/management.—Timber productivity is high to very high, which is highest for the series (appendix E). Timber management opportunities, however, are restricted because of the limited extent and nature of the sites. In this respect, maintenance of water quality is usually a paramount concern.

Other studies.—This habitat type has not been mentioned previously.

ABIES CONCOLOR/BERBERIS REPENS H.T. (ABCO/BERE; WHITE FIR/OREGONGRAPE)

Distribution.—This habitat type, with two recognized phases, occurs throughout the geographical extent of the series. Elevations range from about 5,700 feet (1 735 m) to over 8,000 feet (2 440 m). Exposures are north-facing or otherwise protected, and slopes are gentle to extremely steep. The habitat type is similar in most all respects to the PSME/BERE h.t.

Vegetation.—*Abies concolor* is the indicated climax. Seral associates vary in occurrence by phase.

Undergrowth is typically brushy (fig. 11). Common species include the joint indicators *Berberis* and *Pachistima myrsinites*, as well as *Symphoricarpos oreophilus, Thalictrum fendleri*, and minor amounts of *Osmorhiza chilensis*. Where the ABCO/PHMA h.t. is nearby on somewhat more mesic sites, small amounts of *Physocarpus malvaceus* are also present. Other more mesic habitat types include ABCO/OSCH and the cooler ABLA/BERE. Warmer and drier sites most frequently support woodland or nonforest communities; also the PSME/BERE h.t. is occasionally adjacent.

Figure 11. *Abies concolor/Berberis repens* h.t. on a moderately steep northeast exposure (8,400 feet [2 560 m] elevation) in the western part of the Uinta Mountains near Kamas, Utah. The low, brushy undergrowth consists primarily of *Symphoricarpos oreophilus* and *B. repens.*

***Symphoricarpos oreophilus* (SYOR) phase.**—This phase occupies the warmest and driest exposures and is especially common in the western mountain ranges. Usually *Abies* does not achieve a closed canopy. *Acer grandidentatum* and *Quercus gambelii* are locally important seral associates which are sometimes persistent in the larger canopy openings. Undergrowth is characterized by normally dense *Symphoricarpos* or the presence of persistent *Cercocarpus ledifolius.* In addition to the typal species, *Prunus virginiana* is often present at the lower elevations and *Ceanothus velutinus* at the higher elevations.

***Berberis repens* (BERE) phase.**—The more mesic BERE phase is commonest in the Wasatch Range and southwestern Uinta Mountains. Stand structure is more closed. *Pseudotsuga* is the principal seral associate; occasionally *Populus tremuloides* is present as a seral species. Undergrowth additions are *Amelanchier alnifolia, Aster engelmannii, Stellaria jamesiana*, and sometimes *Carex geyeri.*

Soils.—Our stands have soils that are derived from a variety of substrates (appendix D). Soils are gravelly, and surface soils vary from sandy loams to rather clayey. Normally little surface rock is present, and bare soil is generally absent. The SYOR phase has an average litter depth of 1.0 inches (2.5 cm); that of the BERE phase is 1.4 inches (3.5 cm).

Productivity/management.—Timber productivity is very low, with stockability limitations in the SYOR phase, and low in the BERE phase (appendix E). Very local timber management opportunities exist where other use considerations are not predominant. Shelterwoods best reflect observed patterns of regeneration. Moderate deer use occurs throughout the type.

Other studies.—The ABCO/BERE h.t. has been briefly described from central Utah by Pfister (1972).

Picea engelmannii Series

Distribution.—This series occurs most commonly throughout the more central and eastern Uinta Mountains. It also occupies some of the moistest sites in the Salt Lake City area of the Wasatch Range as well as in the westernmost Uintas. Although most all sites occur within the altitudinal range of *Abies lasiocarpa*, exposures are either too cold or too dry for *Abies*. In general, all aspects are represented and elevations range from about 9,000 feet (2 745 m) to over 11,000 feet (3 350 m) at timberline.

Vegetation/fire history.—*Picea engelmannii* is often very long-lived, frequently attaining ages of greater than 400 years. Fire is an important perturbation: although more frequent at lower elevations, its effect may be more severe at higher elevations where stand establishment can be quite prolonged. Very wet sites often have *Abies lasiocarpa* represented as a climax associate. Several old-growth structural trends are encountered on drier sites. There, reproduction occurs mainly on mineral soil created by upturned root masses, and *Abies* is accidental. For the series, undergrowth varies from a rather diverse assemblage of moist-site species to undergrowth dominated by cold-site species, especially *Vaccinium.*

Below about 10,600 feet (3 230 m) elevation, *Pinus contorta* is usually a major seral associate. *Pinus*, however, can be quite persistent. Where it is persistent, *Picea* usually occurs as scattered individuals, and subsequent *Picea* reproduction is quite sporadic, primarily reflecting the droughty seedbed conditions. *Populus tremuloides* is sometimes an additional seral associate at lower elevations.

Old-growth stands occupying sites above the occurrence of *Pinus* are comprised of largely all-aged *Picea.* Stands vary from fairly continuous to isolated groups of trees, or copses, that are surrounded by meadow communities. Within the timberline zone, stands are similar in most respects to those of the TRSP phase of the ABLA/RIMO h.t.

Pfister (1972) recognized a *Picea engelmannii/Ribes montigenum* h.t., which occurs above the cold limits (about 10,800 feet [3 290 m]) of *Abies lasiocarpa* in southern Utah. One old-growth PIEN/RIMO community was sampled in the southeastern Uintas near 10,900 feet (3 320 m) elevation. Although *Abies* was not represented in the stand, it was nearby on the same substrate, and the site appeared to be sufficiently warm for this species. This stand was placed in the ABLA/RIMO h.t., TRSP phase. Also, several mature stands of *Picea engelmannii/Juniperus communis* communities were sampled in the south-central Uintas. These appeared to have occupied the ABLA/JUCO h.t. and were placed in that group. It is expected that similar correspondences will occur for other stands of either situation. Probably the pure *Picea engelmannii* stands of the northwestern region will also represent the *Abies lasiocarpa* series, with the possible exception of the Deep Creek Range where a major PIEN/RIMO h.t. appears to be present and where *A. lasiocarpa* was not encountered.

Soils.—Soils are derived predominantly from quartziferous materials (appendix D). Most are quite gravelly and typically shallow. Surface soils vary from fairly well-drained sandy loams to very clayey for the moistest sites. Exposed rock ranges from absent or only slight to considerable; it is most common on slopes and at high elevations. Bare soil is normally absent. Litter accumulation is somewhat greater than that of the comparable *Abies lasiocarpa* h.t.'s.

Productivity/management.—Timber productivity is generally low throughout the series (appendix E). The adverse regeneration conditions of high-elevation sites within the series have been discussed by Roe and others (1970). Where environmental factors and growth rates are acceptable, small clearcuts for *Pinus contorta* appear to be the best natural regeneration strategy (guidelines for this species are discussed under the *P. contorta* series, Management section). If *Picea* is desired, partial shade and mineral soil are usually necessary.

The most important values of the series are summer elk habitat (Winn 1976), watershed cover, and wilderness considerations. Use by sheep for shaded bedgrounds is most extensive at the higher elevations wherever open grazing areas are nearby.

Other studies.—Various, mostly dissimilar *Picea engelmannii* h.t.'s have been described from Montana (Pfister and others 1977) and central Idaho (Steele and others 1981). In general, these occupy very cool sites between the *Abies lasiocarpa* and *Pseudotsuga menziesii* series. The *P. engelmannii* series of western Wyoming (Steele and others 1983), as well as the Big Horn Mountains, Wyo. (Hoffman and Alexander 1976), is more similar to that of northern Utah. In addition, one habitat type has been recognized from northern New Mexico (Moir and Ludwig 1979) and, as noted, from southern Utah (Pfister 1972).

PICEA ENGELMANNII/EQUISETUM ARVENSE H.T. (PIEN/EQAR; ENGELMANN SPRUCE/COMMON HORSETAIL)

Distribution.—This minor habitat type occurs in the central Wasatch Range in the vicinity of Salt Lake City, and in isolated locations of the Uinta Mountains. Elevations are near 9,000 feet (2 745 m). The PIEN/EQAR h.t. normally occupies moist to wet streamside terraces that are relatively cool for the area but warm for the series (fig. 12).

Vegetation.—*Picea engelmannii* is the indicated climax. *Pinus contorta* is a minor seral associate in the Uinta Mountains. Normally *Abies lasiocarpa* is a climax associate; however, we concur with Pfister and others (1977) and Steele and others (1983) in the placement of such sites in the *Picea engelmannii* series in that *Picea* appears to have a greater competitive advantage under these very wet environmental conditions. Although *Picea pungens* was not encountered as a climax dominant under such conditions, it can be expected to occur in northern Utah. When present, such sites should be placed in the PIEN/EQAR h.t. for management considerations.

Undergrowth is normally characterized by abundant *Equisetum arvense* and a variable assortment of moist-

Figure 12. Picea engelmannii/Equisetum arvense h.t. is a somewhat unusual type that occurs in the central portion of the Wasatch Range on moist streamside terraces. This stand occurs at 8,750 feet (2 670 m) elevation east of Kamas, Utah. It has an herbaceous undergrowth dominated by *Calamagrostis canadensis*, various species of *Carex, E. arvense*, and *Veratrum californicum*.

site forbs, such as *Aconitum columbianum, Pyrola asarifolia, Saxifraga odontoloma, Senecio triangularis*, species of *Carex* including *C. disperma*, and *Salix*. In addition, in the Uinta Mountains *Calamagrostis canadensis* is characteristically present. *Erigeron peregrinus, Pyrola secunda, Smilacina stellata, Bromus ciliatus, Elymus glaucus*, and species of *Lonicera, Arnica*, and *Geranium* commonly occupy drier microsites. *Ribes montigenum, Sambucus racemosa, Aster engelmannii, Osmorhiza depauperata, Rudbeckia occidentalis*, and *Veratrum californicum* are locally abundant.

In northwestern Utah, the ABLA/BERE h.t., RIMO phase, is often found upslope of the PIEN/EQAR h.t. In the Uinta Mountains, the ABLA/CACA h.t. is sometimes proximate. Similarly the ABLA/VACA or ABLA/VASC h.t.'s are found on better drained sites. Adjacent, wetter sites everywhere normally support *Salix/Carex* communities which usually contain an *Equisetum* component.

Soils.—The substrates of our stands are predominantly alluvium of variable composition, but chiefly granitic or quartziferous (appendix D). Surface soils are normally very moist and locally range in texture from sandy loam to mucky-clays; gravel occurrence is equally variable. Surface rock is sometimes present but bare soil is usually absent. Litter depth averages 2.5 inches (6.5 cm).

Productivity/management.—Timber productivity is low in the Uintas and moderate in the Wasatch Range (appendix E). Sites are extremely fragile. Thus, the principal value of the type is as streamside cover and wildlife habitat.

Other studies.—The PIEN/EQAR h.t. has been described from Montana (Pfister and others 1977), central Idaho (Steele and others 1981), and eastern Idaho, western Wyoming (Steele and others 1983).

PICEA ENGELMANNII/CALTHA LEPTOSEPALA H.T. (PIEN/CALE; ENGELMANN SPRUCE/ELKSLIP MARSHMARIGOLD)

Distribution.—This very local habitat type occurs principally in the southern and western Uinta Mountains. The gentle slopes are cool to cold, often with seasonably high water tables. Elevations range from near 10,000 feet (3 050 m) to over 10,900 feet (3 320 m).

Vegetation.—*Picea engelmannii* is the indicated climax. *Pinus contorta* is locally a major seral associate. Although *Abies lasiocarpa* is sometimes present, individual trees are normally stunted and only occupy drier microsites.

Undergrowth is predominantly herbaceous. In addition to the indicator *Caltha leptosepala*, other common moist- or cold-site species are *Arnica* spp., *Pedicularis bracteosa, P. groenlandica, Polygonum bistortoides, Potentilla* spp., *Sibbaldia procumbens, Trifolium* spp., *Carex atrata, C. scirpoidea, Deschampsia caespitosa, Luzula spicata, Phleum alpinum*, and occasionally *Veronica wormskjoldii, Festuca ovina*, and *Poa alpina*. Species often represented on drier microsites include *Antennaria microphylla, Erigeron peregrinus, Danthonia intermedia, Poa nervosa* and *Trisetum spicatum*. The only common shrubs are *Vaccinium caespitosum* and *V. scoparium*; these also reflect the proximate, drier PIEN/VACA, PIEN/VASC, and ABLA/VASC h.t.'s.

Soils.—Our stands have quartzite or Duchesne sandstone substrates (appendix D). Surface soils are moist and have loamy to clayey textures and local gravel. Subsurface clay-dominated horizons are also usually present. Some surface rock, but little or no bare soil, is present. Litter averages 1.3 inches (3.4 cm) in depth.

Productivity/management.—Timber productivity is low and growth rates are poor (appendix E). For the most part, overstory manipulation usually results in raised water tables and an intensification of insolation and frost heaving, which impedes regeneration. Cattle use is local and particularly intensive near recent stand openings or where grazing areas are nearby.

Other studies.—Steele and others (1983) described this habitat type for western Wyoming.

PICEA ENGLEMANNII/VACCINIUM CAESPITOSUM H.T. (PIEN/VACA; ENGELMANN SPRUCE/DWARF BLUEBERRY)

Distribution.—The PIEN/VACA h.t. occurs throughout the central and eastern Uinta Mountains. Elevations are between 9,600 and 11,100 feet (2 925 and 3 385 m), and occasionally as low as 9,300 feet (2 835 m) on northerly exposures. It is similar to the ABLA/VACA h.t. insofar as sites are dominated by cold air drainage or accumulation. Accordingly, the normally gentle terrain includes such features as basins, benches, ridge slopes, and plateaulike surfaces.

Vegetation.—*Picea engelmannii* is the indicated climax. Below 10,600 feet (3 230 m), *Pinus contorta* is usually a major seral associate. Sometimes it is persistent. *Populus tremuloides* is locally an important seral component at lower elevations only.

Vaccinium caespitosum characterizes a rather diverse undergrowth (fig. 13). At higher elevations, several other cold-site species are fairly common, such as *Lewisia pygmaea, Polygonum bistortoides, Potentilla* spp., *Sibbaldia procumbens, Trifolium* spp., *Deschampsia caespitosum, Luzula spicata, Poa alpina*, and particularly near timberline, *Geum rossii, Carex albo-nigra*, and *Carex scirpoidea*. Occurring throughout the type are *Juniperus communis, Ribes montigenum, Achillea millefolium, Antennaria* spp., *Arnica cordifolia, Epilobium angustifolium, Erigeron peregrinus, Fragaria virginiana, Sedum lanceolatum, Carex rossii, Poa nervosa*, and *Trisetum spicatum*. In addition, *Vaccinium scoparium* is often abundant, reflecting the warmer, proximate PIEN/VASC h.t. Normally, a variety of nonforest communities are adjacent at higher elevations (which are described by Lewis 1970).

Figure 13. *Picea engelmannii/Vaccinium caespitosum* h.t. on gentle topography at high elevations (10,050 feet [3 060 m]) in the eastern Uintas, Ashley National Forest. The undergrowth in this stand is dominated by a mixture of *V. caespitosum* and *Vaccinium scoparium*.

Soils.—Our stands have parent materials that are mainly quartziferous, chiefly quartzite (appendix D). Surface soil textures range from sandy loam to clayey, generally the latter, and gravel is typically present. Surface rock varies from absent to considerable. Bare soil is generally absent. Litter depth averages 1.2 inches (3.1 cm).

Productivity/management.—The principal use of this type is as wildlife habitat for elk as well as a variety of smaller vertebrates (Winn 1976).

Timber productivity is low (appendix E). Management is more feasible where *Pinus contorta* is a major stand component. There, small clearcuts are often the best natural regeneration strategy. In many locations, however, severe frost-pocket conditions may result from such activities, with excessive seedling mortality and stunted initial growth.

Other studies.—This habitat type has been described from Montana by Pfister and others (1977).

PICEA ENGELMANNII/VACCINIUM SCOPARIUM H.T. (PIEN/VASC; ENGELMANN SPRUCE/GROUSE WHORTLEBERRY)

Distribution.—This habitat type is common throughout the central and eastern Uinta Mountains. Elevations range from about 9,600 feet (2 925 m) to 11,200 feet (3 415 m) at timberline. Exposures are typically very cool and dry to moist. As such, the PIEN/VASC h.t. occupies a variety of gentle to moderately steep terrain that encompasses drainage bottoms through middle to upper slopes, as well as broad plateaulike surfaces.

Vegetation.—*Picea engelmannii* is the indicated climax. *Pinus contorta*, which is often persistent, is a major seral associate below 10,600 feet (3 230 m) elevation.

Undergrowth usually consists of a striking cover of *Vaccinium scoparium*. Common species include *Juniperus communis* as well as small amounts of *Ribes montigenum, Achillea millefolium, Arnica cordifolia, Erigeron peregrinus, Potentilla* spp., *Carex rossii, Poa nervosa*, and *Trisetum spicatum. Antennaria* spp., *Polemonium pulcherrimum, Sibbaldia procumbens*, and *Sedum lanceolatum* are more local in occurrence. Colder proximate sites are usually the PIEN/VACA h.t. Warmer habitat types are typically the PICO/VASC h.t. at lower elevations in the north-central area and the ABLA/VASC h.t. elsewhere. The ABLA/RIMO h.t., TRSP phase, typically occurs at higher elevations.

Soils.—In general, the soils of our stands are similar overall to those of the PIEN/VACA h.t. Litter depth, however, is less (1.0 inches [2.6 cm]) and the surface soils are generally coarser, being predominantly gravelly sandy loams.

Productivity/management.—Timber productivity is low (appendix E). Resource management opportunities and considerations are generally similar to those of the PIEN/VACA h.t., but frost-related damage appears to be less critical.

Other studies.—The PIEN/VASC h.t. has been described from western Wyoming (Steele and others 1983) and north-central Wyoming (Hoffman and Alexander 1976). In addition, a somewhat similar *Picea engelmannii/Vaccinium scoparium/Polemonium delicatum* h.t. has been recognized in northern New Mexico by Moir and Ludwig (1979).

Abies lasiocarpa Series

Distribution.—The *Abies lasiocarpa* series occurs throughout the higher mountain ranges of northern Utah and adjacent Idaho (appendix A). In the northwestern region, it occupies all but the warmest of forested exposures above 7,500 to 8,000 feet (2 285 to 2 440 m) elevation. This represents, for example, about 2,500 vertical feet (760 m) in the northern Wasatch Range. Near Salt Lake City it forms the timberline forests to about 10,500 feet (3 200 m) elevation. The series occasionally extends downward to about 6,000 feet (3 200 m) on protected, generally northerly slopes. Topography is typified by both moderate to very steep slopes and gentle uplands. Normally the warmer *Pseudotsuga menziesii* series occurs below. The *Pseudotsuga* series may also occupy the warmest exposures or the driest sites having shallow bedrock within the *A. lasiocarpa* series, except where it may be replaced by the *Abies concolor* series of the southern areas. Persistent shrub communities are also sometimes adjacent on warmer exposures (described by Ream 1964).

The *Abies lasiocarpa* series is represented by extensive forests throughout most of the Uinta Mountains from between about 8,000 and 9,000 feet (2 440 and 2 745 m) elevation to treeline, which is at about 11,000 feet (3 355 m). As such, it occupies all exposures, including steeper canyon and ridge slopes except the driest or exceptionally coldest. The *Abies lasiocarpa* series is often conspicuously absent within the rain shadow area of the north-central Uintas where it is replaced by the *Pinus contorta* or the *Picea engelmannii* series on most all of these dry and cold exposures. Throughout the Uintas, the *A. lasiocarpa* series is also found at lower elevations on especially moist or cool sites within the warmer *Picea pungens* and *Pseudotsuga* series (which generally occupy calcareous-dominated substrates) and the *P. contorta* series, to a lower limit of about 7,500 feet (2 285 m).

Vegetation.—*Abies lasiocarpa* is the indicated climax. A variety of stand conditions are encountered throughout the series, as could be expected given its environmental extent. Pfister (1972) discussed the general structural, successional, and compositional trends of the series, and identified specific patterns that are associated with environmental extremes and more modal conditions. Briefly summarized, these represent three major points:

1. For unfavorable sites, normal succession progresses relatively more slowly, with seral species tending to create the dominant stand aspect.
2. Old-growth stands occupying unfavorable sites tend to be more open; conversely, those of more favorable sites are more closed, being often densely so.
3. Seral associates growing in smaller canopy openings resulting from minor mortality such as windthrow, biological agents, or light fires tend to contribute more significantly to the dominant stand aspect on unfavorable sites than on favorable sites.

The overstory vegetation patterns on the most unfavorable sites are particularly characteristic of specific habitat types or phases, and are discussed where most applicable: for instance, timberline forest conditions with the ABLA/RIMO h.t., TRSP phase.

Nearly all northern Utah tree species are represented as seral associates in the series (appendix B). Of the major species, *Pseudotsuga menziesii* is most important on the warmer exposures in the northwestern region; *Pinus contorta* on similar sites in the Uinta region. Likewise, *Populus tremuloides* occurs throughout the northern Utah area. *Picea engelmannii* is normally associated with cooler exposures. Following major disturbance such as fire, these species are the dominant components of seral stands, although *Abies* is also a major pioneer species on especially mesic exposures.

Typically, late seral stands occupying the more moderate exposures develop a distinct, sometimes very dense component of *Abies* that often includes layered

stems. This component normally approaches an all-aged condition. *Abies* mortality can be extensive, however. This is generally attributed to various decay fungi, and principally the root rot *Fomes annosus* (Nelson 1963).

Two old-growth conditions are especially noteworthy. First, whenever *Picea* is initally a major stand component, the old-growth aspect is dominated by this species. These *Picea* are long lived, 300+ years, and typically large, 40 inches (100 cm) d.b.h. and 100 feet (30 m) high. The understory component of the stand is often dominated by *Abies*, with little representation of *Picea*, except where mineral soil has been bared by upturned root systems. This old-growth aspect is particularly evident in the ABLA/PERA h.t. (PERA phase), the ABLA/RIMO h.t. (THFE phase), and the ABLA/VASC h.t. (ARLA phase). In the above instances, it appears that *Picea* is a long-lived dominant that some authors consider coclimax. The relative inability of *Picea* to establish on its own litter, as demonstrated by Daniel and Schmidt (1972), suggests the use of the *Abies* climax name for this condition.

The second old-growth condition occurs with lower sites in the Uinta Mountains. There, old-growth stands are frequently dominated by *Pinus contorta* and have only a minor *Abies* component. Thus, some stands may be sought at the *Pinus contorta* series. Even though replacement by shade-tolerant species is slow, its progression should be fairly obvious (see also the *Pinus contorta* series). Such circumstances are perhaps better attributed primarily to unfavorable, droughty seedbed conditions for seedling establishment rather than entirely to the presumably frequent incidence of natural surface fires. Although fire will often destroy shade-tolerant associates, it also creates optimum seedbed conditions for these associates.

Soils/climate.—Soils of the *Abies lasiocarpa* series are derived from a variety of substrates (appendix D-1). In general, surface soil textures range from loamy to clayey in the northwestern region, and from sandy loam to loamy in the Uintas. Many surface soils are gravelly and well drained, although those of the ABLA/CACA and ABLA/STAM h.t.'s are seasonally moist and typically clayey. Exposed rock and bare soil are most common in habitat types that are associated with shallow bedrock and with sites near timberline. Litter depth varies, ranging from an average depth of about 2.0 inches (5.0 cm) on the lower, mesic habitat types to about 0.8 inches (2.0 cm) on the higher types.

The most characteristic features of the climate of the *Abies lasiocarpa* series are the overall cool temperatures, frequent summer frosts, and deep snowpack accumulation and lengthy retention (Lawton 1979), all of which create a short growing season. The climatic data from two stations presented in appendix D-2 reflect these conditions.

Fire history.—As noted by Pfister and others (1977), lightning-caused fires in the lower elevation, drier habitat types tend to be more frequent and less harmful than in the moister types. The extent of burning at higher elevations, however, is often restricted by terrain, natural fuel breaks, and moister and cooler burning conditions.

The extensive logging that occurred throughout the Wasatch Range during the late 1800's and the fires that followed had a marked influence on some current stand conditions. Their effect is most apparent in the middle elevation habitat types of the *Abies* series. For example, in the vicinity of Franklin Basin east of Logan, extensive areas were logged for all but the smallest material. Afterward, fires swept through much of the area, destroying residual stems and new regeneration as well as unlogged stands. This was followed by a period of intensive livestock grazing, apparently mostly sheep, which resulted in significant soil loss and compaction and even yet more fires. Many essentially pure stands of *Populus tremuloides* resulted. In many of these, conifers, mainly *A. lasiocarpa*, have only recently become established. This is particularly evident on the less protected exposures of the ABLA/OSCH and ABLA/BERE h.t.'s, where *Pseudotsuga* would normally have been a principal seral associate (as indicated by large, charred stumps and from Bird 1964), and succession to conifer dominance probably would have been fairly rapid. This is not to be interpreted that all stands dominated by *Populus* are clearly seral stages of *A. lasiocarpa* h.t.'s.

Productivity/management.—Within the series, timber productivity is highest in the mesic, midelevation habitat types of northwestern Utah and adjacent Idaho. Upper-moderate to high yield capability occurs in parts of the ABLA/ACRU, ABLA/PERA, the PSME and BERE phases of the ABLA/BERE, and the THFE phase of the ABLA/RIMO h.t.'s (appendix E). Basal area development is also good in these types. With the exception of *Pseudotsuga* in the ABLA/ACRU h.t., either *Picea engelmannii* or *Abies lasiocarpa* is the fastest growing species, as measured by average sample site index. Elsewhere, productivity ranges from low to moderate, and *P. engelmannii* or *Pinus contorta* is the most productive species. In some instances, such as the ABLA/OSCH h.t., dominance by *Populus* normally tends to reduce overall coniferous productivity.

The northwestern region offers good timber management opportunities on the more gentle portions of the above types, as with the ABLA/VAGL and ABLA/ACGL h.t.'s in Idaho. This series includes most of the old-growth stands of this region. In the Uinta Mountains most of the lower part of the series offers good management opportunities, primarily for *Pinus contorta*. Timber management opportunities for other northern Utah types in the series are poorer because of low productivity, adverse regeneration conditions or brush development following overstory manipulation, or conflicting use considerations.

Silvicultural strategies and considerations for regeneration have been discussed in general for the series by Alexander (1974) and Pfister (1972), for *P. contorta* by Lotan (1975a), for *Pseudotsuga* by Ryker (1975), and for *P. engelmannii* by Roe and others (1970). Mineral soil appears to be a prerequisite for good regeneration for all species (Daniel and Schmidt 1972). Furthermore, specific site preparation measures may be necessary to control rhizomatous graminoids or brush, and windthrow is often a special problem (Alexander 1974). Schimpf and others (1980) have provided a current review of

autecological studies relating to the natural regeneration of these species.

Pinus contorta is normally the easiest species to regenerate by both natural and artificial means. Because its cone habit is largely nonserotinous throughout northern Utah, small patch or strip clearcuts are generally best. The more shade-tolerant species are best regenerated under conditions of partial shade. Various shelterwood measures most typically reflect the majority of observed natural stand patterns, particularly for *Pseudotsuga*. These also serve to suppress subsequent *Populus* development. *Populus*, however, may be especially desirable for wildlife forage (Patten and Jones 1977) or as a "nurse" cover for conifer establishment especially when diseased old-growth necessitates clearcutting. Selection methods are sometimes possible for *P. engelmannii*. Smaller patch or strip clearcuts are feasible for all of these species but usually on more protected exposures only; even so, planting is often necessary but is not always successful. Roe and others (1970) discussed the various factors that are potentially troublesome with clearcutting, especially for *P. engelmannii* at higher elevations. These include seedling mortality from direct insolation, moisture stress, frost heaving, cold injury, and damage by vertebrates. The development of competition from *Carex rossii* appears to be especially critical in larger clearcuts.

Shade-tolerant species are the hosts for several diseases, most of which are only local problems and, in general, only affect vigor and growth. The most conspicuous of these are broom rusts (*Stellaria* is an alternate host); if this disease is particularly severe in a stand, clearcutting may be the only available regeneration strategy. Root rots (primarily *Fomes annosus*) and stem decay fungi are very important because of mortality and merchantability losses.

The *Abies lasiocarpa* series provides significant nontimber benefits throughout northern Utah. Esthetic considerations are very important because of the fairly intense, seasonal recreational activities, such as skiing in the Wasatch Range and wilderness values in the higher Uinta Mountains. Watershed protection values are high, and opportunities for water quality and yield management are often major considerations. Seral stands provide summer range and forage for big game and domestic livestock on the more gentle sites. Additionally, the series is habitat for a multitude of other wildlife (Collins and others 1978; Deschamp and others 1979; Winn 1976).

ABIES LASIOCARPA/CALAMAGROSTIS CANADENSIS H.T.(ABLA/CACA; SUBALPINE FIR/BLUEJOINT REEDGRASS)

Distribution.—This habitat type, which is always associated with seasonally moist or saturated surface soils, is found locally throughout the Uinta Mountains. Elevations range from about 7,700 feet (2 350 m) along northerly stream courses, to near 10,000 feet (3 050 m). Exposures are gentle and include alluvial terraces as well as benchlands, ridges, and other related glacial and fluvial terrain. The ABLA/CACA h.t. also might be encountered at the higher elevations of the Wasatch Range in the vicinity of Salt Lake City.

Vegetation.—*Abies lasiocarpa* is the indicated climax. The dominant components of most seral stands are *Pinus contorta* and, locally, *Populus tremuloides*. *Picea engelmannii* is a persistent seral associate on particularly wet sites. *Picea pungens* is occasionally present as a minor associate at lower elevations. *Abies* and *P. engelmannii* are sometimes only poorly represented as stunted or very slow-growing individuals in old-growth stands of persistent *Pinus contorta*. These prolonged seral conditions typically occur with sites that are not too wet; they are discussed separately as the PICO/CACA c.t.

Although the undergrowth assemblage is diverse, *Calamagrostis* usually dominates the swardlike herbaceous component. On seeps or very moist streamside sites at lower elevations the undergrowth can include *Alnus tenuifolia*, *Pyrola asarifolia*, or *Cinna latifolia*, whereas *Caltha leptosepala*, *Polygonum bistortoides*, *Carex atrata*, *Deschampsia caespitosa*, *Luzula parviflora*, *Phleum alpina*, or *Poa reflexa* can be represented at higher elevations. Herbs, which occur commonly throughout the type on drier microsites, include *Achillea millefolium*, *Arnica cordifolia*, *Fragaria virginiana*, *Galium boreale*, *Geranium richardsonii*, *Bromus ciliatus*, *Trisetum spicatum*, as well as species of *Erigeron*, *Osmorhiza*, and *Potentilla*. Similar in occurrence are the shrubs *Juniperus communis*, *Lonicera involucrata*, *Ribes montigenum*, *Berberis repens*, *Vaccinium caespitosum*, or *V. scoparium*. The latter three species typically reflect the most common adjacent *Abies lasiocarpa* h.t.'s. Especially noteworthy are *Linnaea borealis*, a species that is sometimes abundant on cool microsites at lower elevations, and minor amounts of *Equisetum arvense*, which indicates the proximate PIEN/EQAR h.t.

Soils.—Our stands have quartzite as an exclusive soil parent material (appendix D). Permanently wet sites (seeps) have mucky surface soils below a typically thick organic layer. Better drained sites have a loamy surface soil texture, and often gravel. High water table conditions are probably associated with argillic horizons, as is the case for the PICO/CACA c.t. Surface rock and bare soil are usually absent. Litter averages 1.2 inches (3.0 cm) in depth, excluding humus.

Productivity/management.—Timber productivity is low (appendix E). Timber activities should be limited to drier sites. On wet sites, overstory manipulation generally results in windthrow, equipment problems, and raised water tables where regeneration success is very sporadic.

The ABLA/CACA h.t. is an important habitat segment for big game (Winn 1976). Domestic livestock use is locally variable.

Other studies.—The ABLA/CACA h.t. has been described for Montana by Pfister and others (1977); central Idaho by Steele and others (1981); and in eastern Idaho and western Wyoming by Steele and others (1983). These authors have also recognized a *Vaccinium caespitosum* phase which generally reflects a cooler temperature regime of lower elevations. Five of our 13 sample stands, including the PICO/CACA c.t., might be considered to represent such a phase. The remaining stands would then comprise a CACA phase.

ABIES LASIOCARPA/STREPTOPUS AMPLEXIFOLIUS H.T. (ABLA/STAM; SUBALPINE FIR/CLASPLEAF TWISTED-STALK)

Distribution.—ABLA/STAM is an incidental habitat type in northern Utah that occupies very moist slopes and alluvial terraces. It can be expected to occur very locally at midelevations of the *Abies lasiocarpa* series in the Uinta Mountains and possibly in the Wasatch Range near Salt Lake City. Elevations appear to be higher than the more common ABLA/CACA and PIEN/EQAR h.t.'s.

Vegetation.—*Abies lasiocarpa* is the indicated climax. Apparently *Picea engelmannii* is a persistent seral dominant and *Pinus contorta* is a minor seral associate occurring only on drier microsites.

Undergrowth is typified by a diverse assemblage of moist-site herbs, such as the joint indicators *Streptopus* and *Senecio triangularis*. The latter is more abundant in open, seral stands. Others include *Arnica latifolia, Mertensia ciliata, Osmorhiza depauperata, Saxifraga odontoloma, Bromus ciliatus*, and *Luzula parviflora*. Drier microsites contain *Ribes montigenum, Vaccinium scoparium, Pyrola secunda*, and *Carex rossii*. Proximate, drier sites are usually the ABLA/VASC h.t.

Soils.—Our sample stands have quartzite parent material. The surface textures are clayey and include considerable organic matter. Some coarse fragments are typically present, both in the shallow soil and on the surface. Litter depth averages 2.9 inches (7.3 cm) but is quite variable.

Productivity/management.—Timber productivity appears to be moderate, but timber management opportunities are extremely limited because of the moistness and rarity of the habitat type.

Other studies.—The ABLA/STAM h.t. is common in central Idaho, where it is described in greater detail by Steele and others (1981). It also extends into western Wyoming (Steele and others 1983).

ABIES LASIOCARPA/ACTAEA RUBRA H.T. (ABLA/ACRU; SUBALPINE FIR/BANEBERRY)

Distribution.—This habitat type is locally common in the canyons of the Wasatch Range of Utah and Idaho, and northward (Steele and others 1983). It is infrequently encountered elsewhere in northern Utah. Typically, sites are very moist northerly exposures on lower and middle slope positions. Steepness ranges from moderate to very steep, and elevations are between about 6,000 and 7,000 feet (1 830 and 2 135 m).

Vegetation.—*Abies lasiocarpa* is the indicated climax. The primary seral dominant is *Pseudotsuga* and locally, at higher elevations, *Picea engelmannii* and *Populus tremuloides*. *Abies* develops fairly rapidly although large *Pseudotsuga* tend to dominate the old-growth aspect.

Undergrowth is usually brushy, with a lush herbaceous component. Shrubs include *Amelanchier alnifolia, Berberis repens, Pachistima myrsinites, Prunus virginiana, Symphoricarpos oreophilus*, and, at lower elevations, *Physocarpus malvaceus*. In addition to *Actaea* common herbs are *Agastache urticifolia, Aquilegia coerulea, Arnica cordifolia, Aster engelmannii, Clematis columbiana, Disporum trachycarpum, Fragaria vesca, Mitella stauropetala, Thalictrum fendleri*, and species of *Galium, Lathyrus*, and *Osmorhiza*. *Carex geyeri* may also be present.

Drier, adjacent habitat types are most often ABLA/PHMA, ABLA/ACGL, ABLA/BERE, and on much warmer exposures at higher elevations, ABLA/OSCH. When ABLA/ACRU occurs within the upper zones of the *Abies concolor* and *Pseudotsuga menziesii* series, proximate sites are the respective habitat types of these series.

Soils.—Typically, soils are deep and moist. In our stands parent materials are quartziferous or sometimes calcareous (appendix D). Surface soils range from loamy to clayey, and some gravel is generally present. Surface rock and bare soil are usually absent. Litter depth averages 2.0 inches (5.1 cm). A few soils appeared to be unstable and might present engineering problems.

Productivity/management.—Timber productivity is moderate to high, representing one of the highest average values of the series (appendix E). Nevertheless, timber management has limited potential because the type is scarce and other uses conflict, especially esthetics. Whenever timber management is feasible, *Pseudotsuga*, the most productive species, might be favored by heavy shelterwood cuts.

The ABLA/ACRU h.t. provides important deer habitat and watershed protection.

Other studies.—Steele and others (1983) described this habitat type from eastern Idaho and western Wyoming. Cooper's (1975) *Abies lasiocarpa/Galium triflorum* h.t. appears to fall into our ABLA/ACRU h.t. In Montana, the ABLA/GATR h.t., which is described by Pfister and others (1977), is similar in some respects to the ABLA/ACRU h.t. of northern Utah.

ABIES LASIOCARPA/PHYSOCARPUS MALVACEUS H.T. (ABLA/PHMA; SUBALPINE FIR/NINEBARK)

Distribution.—This warm, fairly moist habitat type occurs throughout the Wasatch Range of Utah and Idaho, but it is most common toward the southern portion. It is infrequent elsewhere, except in the extreme northwestern Uinta Mountains near the Weber River. The ABLA/PHMA h.t. occupies northerly, lower to middle canyon slopes that are moderate to very steep. Elevations are between about 6,600 and 7,800 feet (2 010 and 2 375 m).

Vegetation.—*Abies lasiocarpa* is the indicated climax. Seral stands are usually dominated by *Pseudotsuga*, which rapidly develops a closed canopy. Locally, *Abies concolor* and *Picea engelmannii* are additional major seral associates. *Populus tremuloides* and *Acer grandidentatum* are minor seral associates that are also local in distribution. Old-growth stands appear fairly similar to those of the ABLA/ACRU h.t.

The shrubby undergrowth is characterized by a normally dense *Physocarpus* layer. Other common shrubs include *Amelanchier alnifolia, Berberis repens, Pachistima myrsinites, Rosa* spp., and *Symphoricarpos oreophilus*. Cooler sites may also have *Acer glabrum* or *Sorbus scopulina*. The herbaceous component typically includes *Aquilegia coerulea, Aster engelmannii, Clematis columbiana, Fragaria vesca, Mitella stauropetala,*

Osmorhiza spp., *Pyrola secunda, Thalictrum fendleri, Viola adunca*, and, when the ABLA/ACRU h.t. is adjacent on moister sites, minor amounts of *Actaea rubra*.

Nearby warmer habitat types include ABCO/PHMA and PSME/PHMA or, if markedly drier, the ABLA/BERE, ABCO/BERE and PSME/BERE h.t.'s. Cooler exposures are typically the ABLA/ACGL h.t.

Soils.—Parent materials are usually diverse, reflecting the colluvial landforms that this habitat type principally occupies. Quartziferous fragments are often a major component (appendix D). Gravel is normally present, sometimes in considerable volume. Surface soils range from loamy to clayey in texture. Surface rock and bare soil are usually absent. Litter averages 1.5 inches (3.8 cm).

Productivity/management.—Timber productivity is moderate (appendix E). Management options and considerations are essentially similar to those of the ABLA/ACRU h.t., with the exception of problems created by the generally steeper slopes and the much greater probability of excessive brush development following overstory removal.

Other studies.—Steele and others (1983) have described this habitat type from eastern Idaho and western Wyoming.

ABIES LASIOCARPA/ACER GLABRUM H.T. (ABLA/ACGL; SUBALPINE FIR/MOUNTAIN MAPLE)

Distribution.—This cool, fairly moist habitat type is found principally in the Wasatch Range of northern Utah and adjacent Idaho. Like the PSME/ACGL h.t., topographic features of the ABLA/ACGL h.t. provide rapid drainage of cold air. Typically, the sites are moderate to very steep northerly canyon slopes. Westerly exposures also occur but are usually associated with streamsides or ravines. Elevations range from 6,500 feet (1 980 m) to 8,000 feet (2 440 m); however, the habitat type also extends downward locally to about 5,900 feet (1 800 m).

The ABLA/ACGL h.t. is very rare in the Uinta Mountains. It was sampled in a canyon bottom at 8,200 feet (2 500 m) elevation in the northeastern area as well as at 9,500 feet (2 895 m) occupying a steep midslope in the south-central area.

Vegetation.—*Abies lasiocarpa* is the indicated climax. Of the many seral associates which are represented with the type (appendix B), *Pinus contorta* and *Populus tremuloides* occur locally with *Pseudotsuga*, the principal seral dominant. Minor components include *Acer grandidentatum, Picea engelmannii*, and *Populus angustifolia*; these are generally associated with lower, higher, or streamside-proximate sites, respectively.

Undergrowth is normally quite shrubby. Tall members include *Amelanchier alnifolia, Acer glabrum*, and *Sorbus scopulina*; the latter has been adopted as a coindicator with *Acer* to correspond with the treatment of the type by Steele and others (1983). Low shrub components include *Berberis repens, Pachistima myrsinites, Rosa* spp., and *Symphoricarpos oreophilus*. The undergrowth also includes a relatively rich herbaceous assemblage; commonly represented are *Aquilegia coerulea, Arnica cordifolia, Aster engelmannii, Fragaria vesca, Goodyera oblongifolia, Mitella stauropetala, Osmorhiza* spp., *Pyrola secunda, Silene menziesii, Thalictrum fendleri*, and *Carex rossii*. Also, *Rubus parviflorus* and *Calamagrostis rubescens* are locally abundant.

Because the ABLA/ACGL h.t. is relatively cool and moist for the lower *Abies lasiocarpa* series, a variety of habitat types are adjacent. The warmer of these include ABLA/PHMA, ABCO/PHMA, PSME/ACGL, and PSME/PHMA, as well as the moister ABLA/ACRU. Drier sites are ABLA/BERE, ABCO/BERE, or PSME/BERE. In Idaho, the ABLA/VAGL and drier ABLA/CARU h.t.'s are typically located upslope.

Soils.—Although the soils of our stands are associated with a variety of substrates, quartziferous-dominated materials are the most common (appendix D). The gravelly surface soils also vary, but finer textures predominate. Surface rock and bare soil are generally absent. Litter averages 2.2 inches (5.5 cm) in depth.

Productivity/management.—Timber productivity is moderate (appendix E). Management guidelines are similar to those of the ABLA/ACRU h.t., but slopes are usually quite steep. Opportunities for timber management are generally better in the Idaho areas.

Other studies.—Steele and others (1983) recognize this habitat type in eastern Idaho and western Wyoming as the *Pachistima myrsinites* phase. This serves as a geographical distinction from the *Acer glabrum* phase of central Idaho (Steele and others 1981).

ABIES LASIOCARPA/VACCINIUM CAESPITOSUM H.T. (ABLA/VACA; SUBALPINE FIR/DWARF BLUEBERRY)

Distribution.—In northern Utah, the ABLA/VACA h.t. is apparently restricted to the Uinta Mountains. Elevations range from about 8,600 to 10,000 feet (2 620 to 3 050 m). The type occurs especially on terrain conducive to accumulating cold air. Topography varies, typically encompassing canyon benches and steep slopes, plateaulike surfaces, and adjacent upper slope areas, as well as the undulate terrain of glacial till.

Vegetation.—*Abies lasiocarpa* is the indicated climax. The dominant component of most seral stands is *Pinus contorta*, but *Picea engelmannii* and *Populus tremuloides* are often important seral associates. *Pseudotsuga*, a minor seral species, is restricted to canyon slopes. As is the case with the other subalpine habitat types where *Pinus contorta* can be a persistent seral species, *Abies lasiocarpa* and *Picea engelmannii* are sometimes present only as stunted or very slow-growing individuals.

Undergrowth typically includes small amounts of *Achillea millefolium, Arnica cordifolia, Epilobium angustifolium, Fragaria virginiana, Galium boreale, Potentilla* spp., *Pyrola secunda, Stellaria jamesiana, Bromus ciliatus, Carex rossii, Poa nervosa*, and *Trisetum sicatum*. In addition, *Carex geyeri* is sometimes abundant at lower and *Sibbaldia procumbens* at higher elevations. The most common shrubs are *Juniperus communis, Vaccinium scoparium, Ribes montigenum*, and at lower elevations, *Berberis repens* or *Pachistima myrsinites*. All of these species reflect warmer, proximate habitat types.

Normally *Vaccinium caespitosum* is represented with sufficient coverage to clearly delineate a site as the ABLA/VACA h.t. In especially depauperate undergrowths or at lower elevations, however, this species occurs mainly as isolated stems. Nevertheless, in many of these instances its presence generally reflects an influence of cold air; any such sites, therefore, should be considered as an ABLA/VACA h.t.

Soils.—Our stands have soil parent materials that are either wholly quartzite or predominantly quartziferous (appendix D). Surface soils range from sandy loams to clay loams but are mainly coarse-textured. Gravel content and surface rock are often considerable but bare soil is normally absent. Average litter depth is 1.3 inches (3.2 cm).

Productivity/management.—Timber productivity is low (appendix E). Seedling growth is poor and reflects the exceptionally frosty environment. Because of this, *Pinus contorta* is the best species for management, and is the easiest to regenerate.

Wildlife and livestock use is local; sites adjacent to meadows are particularly critical for cover.

Other studies.—In Montana, the ABLA/VACA h.t. has been described by Pfister and others (1977). Kerr and Henderson (1979) described an ABLA/VACA h.t. from central Utah that is overall similar to our stands containing *Berberis* or *Pachistima.*

ABIES LASIOCARPA/VACCINIUM GLOBULARE H.T. (ABLA/VAGL; SUBALPINE FIR/BLUE HUCKLEBERRY)

Distribution.—The ABLA/VAGL h.t. occurs infrequently in the northernmost Wasatch Range and westernmost Uinta Mountains (appendix A). It increases in extent northward through southeastern Idaho and adjacent Wyoming where it is recognized by Steele and others (1983). Kerr and Henderson (1979) described an *Abies lasiocarpa/Vaccinium membranaceum* h.t. from central Utah which corresponds to our ABLA/VAGL h.t.

ABLA/VAGL h.t. occupies a variety of cool and moderately moist, typically north-facing exposures between about 7,200 feet (2 195 m) and 8,800 feet (2 680 m) elevation. Slopes range from gentle to very steep, but are most typically moderate in steepness.

Vegetation.—*Abies lasiocarpa* is the indicated climax. Most seral stands are dominated by *Picea engelmannii*, with *Pinus contorta* or *Pseudotsuga* as an additional seral associate. Most are also distinctly even-aged in appearance, being of fire origin. *Abies* develops rather slowly on some sites.

Undergrowth is characterized by abundant cover of *Vaccinium*, which for the northern Utah area is unique in appearance (fig. 14). Other common shrubs are *Pachistima myrsinites, Sorbus scopulina*, and *Ribes montigenum. Arnica latifolia* and *Pedicularis racemosa* are usually the most abundant herbs; others include *Aquilegia coerulea, Arnica cordifolia, Aster engelmannii, Osmorhiza* spp., *Pyrola secunda*, and *Carex rossii.*

The ABLA/VAGL h.t. gradually disappears from the southeastern Idaho landscape southward through northern Utah. Topographically, it appears to be replaced by the ABLA/PERA h.t. and the RIMO phase of the ABLA/BERE h.t.; these generally encompass the more moist and cooler portions of the ABLA/VAGL landscape.

Figure 14. *Abies lasiocarpa/Vaccinium globulare* h.t. on a gentle northerly exposure toward the north end of the Bear River Range on the Wasatch-Cache National Forest (8,100 feet [2 470 m] elevation). The abundance of *V. globulare* in the undergrowth is typical of this type.

Soils.—The soils of our stands are almost exclusively associated with quartzite or other quartziferous-dominant parent materials (appendix D). Surface soils are expected to be the most acidic of the lower *Abies lasiocarpa* h.t.'s. Where calcareous-dominated substrates are close by, the transition from ABLA/VAGL to ABLA/BERE is often striking. The predominant surface soil texture is clayey; soils are normally gravelly. Little surface rock and bare soil are present, although occasionally a considerable amount of rock is encountered. Litter depth averages 1.9 inches (4.8 cm).

Productivity/management.—Timber productivity is mostly moderate (appendix E). Opportunities for timber management are generally good in Idaho wherever slopes are not too steep. Management alternatives include *Pinus contorta, Pseudotsuga*, or *Picea engelmannii.* Natural regeneration strategies vary from shelterwoods to small clearcuts, depending on the present and desired composition. Planting might be very successful on the warmer, protected sites.

Wildlife use is light to moderate. Of special significance is *Vaccinium* fruit production: this provides a unique resource for both wildlife and local residents alike. Silvicultural treatments that increase direct sunlight appear to enhance berry production. Also, *Vaccinium* density might be increased by light surface fires (Miller 1977).

Other studies.—In Montana, the ABLA/VAGL h.t. has been described by Pfister and others (1977); it is most common in the south-central and southwestern sections of the State. Steele and others (1983) have recognized two phases of ABLA/VAGL in eastern Idaho and western Wyoming. The cooler and higher phase is characterized by at least 25 percent cover of *Vaccinium*

scoparium. Some sites in the Uinta Mountains may correspond to this phase. The other phase, *Pachistima myrsinites*, serves as a geographical distinction from the VAGL phase of central Idaho (Steele and others 1981).

ABIES LASIOCARPA/VACCINIUM SCOPARIUM H.T. (ABLA/VASC; SUBALPINE FIR/GROUSE WHORTLEBERRY)

Distribution.—The ABLA/VASC h.t. occurs throughout most of the Uinta Mountains. Elevations range from about 9,000 feet (2 745 m) to just below 11,000 feet (3 355 m) near treeline. The relatively cool to cold exposures are variable in moistness; these conditions are reflected by the three recognized phases. In general, the type encompasses the extensive plateaulike surfaces and basin and ridge slopes which so characterize the central massif. ABLA/VASC is the most ubiquitous habitat type of the upper Uintas, but it is relatively uncommon in the north-central area. There, it normally occupies only the most moderate sites within the rain shadow area, being largely replaced by the PIEN/VASC h.t. on cooler exposures and the PICO/VASC h.t. on warmer exposures.

The ABLA/VASC h.t. was not found in northwestern Utah. In Idaho, it was sampled from only a few isolated locations in the Wasatch Range (Copenhagen Basin). There, exposures were gentle, northeasterly slopes near 8,500 feet (2 590 m) elevation, with quartzite substrates.

Vegetation.—*Abies lasiocarpa* is the indicated climax. Two extreme overstory conditions are commonly encountered with old-growth stands. Whenever *Picea engelmannii* is initially a major seral component, it tends to dominate the overall old-growth aspect, with an often dense *Abies* understory of layered stems. Such conditions are especially evident at the higher, timberline extent of the VASC phase, or the most moist portions of the ARLA phase. Elsewhere in the Uintas, *Pinus contorta* is the primary seral associate. On particularly warm-dry sites, *Pinus* can be the dominant aspect of old-growth stands; sometimes shade-tolerant species such as *Picea* have only poor representation and a slow rate of placement. *Populus tremuloides* is nominally represented at lower elevations.

A sweeping high carpet of *V. scoparium* typifies the undergrowth (fig. 15). Small amounts of *Achillea millefolium, Epilobium angustifolium, Hieracium* spp., *Carex rossii, Poa nervosa, Trisetum spicatum*, and the conspicuous *Arnica cordifolia* are represented throughout the type. *Vaccinium caespitosum* and either *Pachistima myrsinites* or *Berberis repens* are often present also, reflecting their presence in adjacent habitat types.

***Arnica latifolia* (ARLA) phase.**—This phase, typically the moistest, is chiefly absent from the southern Uinta Mountains. Elevations range from 9,000 feet (2 745 m) to near 10,600 feet (3 230 m). Exposures are northwest- to northeast-facing, moderate lower slopes or occasionally undulate surfaces. Sites otherwise are very protected.

Normally *P. engelmannii* is the dominant component of late seral stands. Undergrowth is generally dominated by *V. scoparium*. In addition to the typal species and an often abundant cover of *A. latifolia*, other common herbs include *Hieracium gracilis, Pedicularis racemosa, Pyrola*

Figure 15. *Abies lasiocarpa/Vaccinium scoparium* h.t. in Copenhagen Basin in the northern portion of the Bear River Range, at an elevation of 8,600 feet (2 620 m). The low-shrub and herbaceous undergrowth consists of a considerable mixture of species of which *V. scoparium* is dominant.

secunda, and species of *Erigeron* and *Osmorhiza*. Also, *Carex geyeri* is occasionally present on the warmer exposures. The presence of *Ribes montigenum* sometimes reflects the adjacent, drier RIMO phase of the ABLA/BERE h.t.

***Carex geyeri* (CAGE) phase.**—The CAGE phase occurs in the western and occasionally in the eastern areas. Relatively warm and dry, it typically occupies gentle, northeasterly to southerly slopes that are typically well drained. Elevations are between 8,700 and 10,100 feet (2 650 and 3 080 m).

Principal seral associates are *P. contorta* and, to a lesser extent, *Carex* component. In addition to the typal species, *Juniperus communis, Hieracium* typal species, *Juniperus communis, Hieracium albiflorum, Osmorhiza* spp., *Pedicularis racemosa, Pyrola secunda, Stellaria jamesiana*, and *Elymus glaucus* are commonly represented. *Calamagrostis rubescens* is also sometimes abundant in the eastern area. Most warmer exposures are the CAGE phase of the ABLA/BERE h.t., whereas cooler sites are generally the VASC phase.

***Vaccinium scoparium* (VASC) phase.**—This phase occurs throughout the Uinta Mountains and often forms the moderately moist timberline forests. Exposures, elevations, and undergrowth characteristics are typical of the type, although the average coverage of *V. scoparium* is somewhat less than that of the other phases. Seral associates are *P. contorta* and *P. engelmannii*, the former being absent from the highest elevations and the latter from the lowest elevations of the phase. Undergrowth often includes *Ribes montigenum* and *Juniperus communis*. These species commonly reflect proximate habitat types: at the higher elevations the more exposed, drier TRSP phase of the ABLA/RIMO h.t.; and at the lower elevations in the southern area, the much warmer and drier ABLA/JUCO h.t. Elsewhere, the ABLA/BERE h.t. occupies the warmer exposures.

Soils.—Our stands are almost exclusively associated with quartziferous-dominated substrates (appendix D). These are derived primarily from quartzite, although sandstone, conglomerate, or shale- or limestone-quartzite sources are also encountered. In general, substrates are shallow residuals or glacier-related in origin. Most soils contain considerable gravel. Surface soils range from sandy loams to clays. Exposed rock varies from absent to very considerable and bare soil is usually absent. The average litter depth ranges from 0.7 inches (1.9 cm) in the CAGE phase to 1.3 inches (3.2 cm) in the ARLA phase.

Productivity/management.—Timber productivity is low to moderate (appendix E). While the VASC and ARLA phases include the highest associated values, the CAGE phase has the highest average productivity. Opportunities for timber management are generally good except on most high-elevation sites and sometimes the moistest sites of the ARLA phase where growth rates are slow. Usually, *Pinus contorta* is the principal timber species, with small clearcuts yielding adequate regeneration. Partial shade and mineral soil are normally required for *Picea engelmannii* regeneration. Special site preparation measures may be necessary in the CAGE phase to reduce competition from this rhizomatous sedge.

Recent studies have shown that big game use of such coniferous forest types varies locally. Working in the southeastern area, Collins and others (1978) observed that elk used the type primarily as cover for travel and resting. Also, the *Vaccinium* browse, herbs, and late-season mushrooms provided alternative forage to preferred feeding habitats such as wet meadows and recent clearcuts. Similar use by deer was observed in the same area by Deschamp and others (1979), except that forbs (*Arnica cordifolia* in particular) contributed more to their diet. Winn (1976), working in the north-central area, identified somewhat similar ungulate presence as well as that of a multitude of avian and mammal species. Domestic livestock use is typically local.

Water yield is an especially important resource; this habitat type is more amenable than others to silvicultural activities intended to improve water yields (Leaf 1975).

Other studies.—ABLA/VASC h.t.'s are encountered throughout the Rocky Mountains: from British Columbia (McLean 1970), western Washington, and northern Idaho (Daubenmire and Daubenmire 1968) through north-central Wyoming (Hoffman and Alexander 1976), and southward to northern New Mexico (Moir and Ludwig 1979). The ABLA/VASC h.t. of the Uinta Mountains was initially described by Pfister (1972), who also discussed the type in relation to elevational distribution. In addition, Reed (1976) recognized a broader concept of the type, which includes our PIEN/VASC h.t.

The VASC phase occurs throughout the above areas, but the ARLA and CAGE phases have not been previously mentioned. The environment of the ARLA phase, however, appears to be quite similar to that of the *Thalictrum occidentale* phase in Montana described by Pfister and others (1977). The *Calamagrostis rubescens* (CARU) phase recognized in Montana (Pfister and others 1977) and in Idaho and western Wyoming (Steele and others 1981, 1983; Cooper 1975) is somewhat similar to our CAGE phase. In these areas, *Carex geyeri* is often a codominant undergrowth member in drier situations of the CARU phase. In the eastern Uintas, the CAGE phase sometimes includes *C. rubescens* as a major component. Also, *C. geyeri* occurs in the lower part of the ABLA/VASC h.t. of southern Wyoming (Wirsing and Alexander 1975).

ABIES LASIOCARPA/CALAMAGROSTIS RUBESCENS H.T. (ABLA/CARU; SUBALPINE FIR/PINEGRASS)

Distribution.—ABLA/CARU, a relatively cool-dry habitat type, is found locally in southeastern Idaho, southward through the eastern flank of the Wasatch Range (the Bear River Range) to the vicinity of Logan, Utah. In this area, it primarily occupies west- to east-facing canyon ridge slopes of gentle to moderate relief at elevations between about 6,900 and 7,600 feet (2 105 and 2 315 m). The ABLA/CARU h.t. is also locally extensive in the easternmost Uinta Mountains. Here it occurs on gentle lower slopes and benches at all exposures from 8,000 feet (2 440 m) to 8,500 feet (2 590 m), or occasionally broad ridgetops to 9,000 feet elevation (2 745 m). *C. rubescens* occurs sporadically through the westernmost Uinta Mountains; it has been observed in the South Fork of the Provo River and Current Creek drainages.

Vegetation.—*Abies lasiocarpa* is the indicated climax. *Pinus contorta* is a major seral dominant, as is more locally *Pseudotsuga*. Usually *Populus tremuloides* is a minor seral associate.

Throughout northern Utah, stands are occasionally encountered within the *Abies lasiocarpa* zone where *A. lasiocarpa* is only poorly represented or absent, and *P. contorta* is the principal or only tree present. *Abies lasiocarpa* is clearly the indicated climax on such sites in northwestern Utah and adjacent Idaho. The successional dynamics of such stands in the Uintas are more questionable; all evidence suggests, however, that *Abies* is also the indicated climax. The three sample stands having these conditions have therefore been included in this series; it is expected that other PICO/CARU communities will also correspond to the *A. lasiocarpa* series.

Undergrowth appearance is strikingly swardlike; it is normally dominated by abundant *Calamagrostis*, and sometimes *Carex geyeri* as well. Other common but minor species include *Amelanchier alnifolia, Berberis repens, Pachistima myrsinites, Rosa nutkana, Arnica cordifolia, Hieracium albiflorum, Osmorhiza* spp., *Viola adunca, Carex rossii, Poa nervosa*, and *Juniperus communis* (Uinta Mountains). The ABLA/BERE h.t. is most frequently adjacent, particularly where substrates are predominantly calcareous or where soils are more shallow and perhaps more gravelly.

Soils.—The soils of our stands are derived from either quartzite substrates or other quartziferous-dominated materials (appendix D). Surface soil textures range from loamy to clayey; normally some gravel is present in the profile. Exposed rock and soil are generally absent. Litter depth averages 1.2 inches (3.1 cm).

Productivity/management.—Timber productivity ranges from low to moderate, but chiefly the latter (appendix E). Opportunities for timber management are generally good although not especially extensive. *Pinus contorta* is the principal management species; when present, *Pseudotsuga* presents additional management possibilities. Regeneration by small clearcuts, or clearcutting with planting, is usually adequate for *Pinus*, but partial shade should enhance *Pseudotsuga* regeneration. In addition, special site preparation measures may be necessary because of the rhizomatous nature of *Calamagrostis* and *Carex geyeri*.

Wildlife and livestock use is light to moderate.

Other studies.—The ABLA/CARU h.t. has been described from Montana (Pfister and others 1977), central Idaho (Steele and others 1981), and eastern Idaho—western Wyoming (Steele and others 1983). Northern Utah is apparently the southernmost extent of the habitat type.

Steele and others (1983) have recognized two phases: the *Pachistima myrsinites* phase, where *Pseudotsuga* and shrub species are more common, and the *C. rubescens* phase, which has *Pinus contorta* as the major seral associate and less conspicuous shrubs. Both phases are probably present in northern Utah even though not formally described.

ABIES LASIOCARPA/PEDICULARIS RACEMOSA H.T. (ABLA/PERA; SUBALPINE FIR/SICKLETOP PEDICULARIS)

Distribution.—Represented by two phases and a total of 66 sample stands, this cool, moist habitat type is quite common at higher elevations in the Wasatch Range of northern Utah and adjacent Idaho, generally between 7,000 and 8,800 feet (2 135 and 2 680 m). This area represents the geographic center of the type. It occasionally is found in the westernmost Uinta Mountains between 8,200 and 9,600 feet (2 500 and 2 925 m) elevation on northerly, gentle to moderately steep exposures.

Within the study area, the lower part of the ABLA/PERA h.t. encompasses landscapes similar to that of the ABLA/VAGL h.t.; a type that is largely absent in Utah but common farther north (Steele and others 1983). The upper part of the ABLA/PERE h.t. is fairly similar to the landscape of the ABLA/VASC h.t., which is also common to the north as well as to the east in the Uintas.

Vegetation.—*Abies lasiocarpa* is the indicated climax. *Picea engelmannii, Pinus contorta*, and *Populus tremuloides* occur as associates locally throughout both phases. *Pseudotsuga* is used as a phasal indicator.

Undergrowth varies by phase. In addition to *Pedicularis*, which is often abundant, *Pachistima myrsinites, Arnica cordifolia, Aster engelmannii, Fragaria vesca* (or *F. virginiana*), *Geranium viscosissimum, Hieracium albiflorum, Osmorhiza* spp., *Pyrola secunda, Stellaria jamesiana, Carex rossii*, and *Poa nervosa* are usually present (fig. 16). Although less frequent, *Ceanothus velutinus, Shepherdia canadensis, Arnica latifolia*, and *Lathyrus lanszwertii* are nevertheless conspicuous when present.

Figure 16. *Abies lasiocarpa/Pedicularis racemosa* h.t. is a prominent in the Wasatch Range. This stand occurs on a moderate southwesterly exposure at an elevation of 7,200 feet (2 200 m), with *P. racemosa, Symphoricarpos oreophilus, Arnica cordifolia*, and *Thalictrum fendleri* prominent in the undergrowth.

Pseudotsuga menziesii **(PSME) phase.**—Although this relatively warm and dry phase occurs throughout the range of the type, it is most common in southeastern Idaho. The PSME phase is delineated by the presence or potential presence of *Pseudotsuga* as evidenced by the occurrence of the local environmental range of *Pseudotsuga*, including its geological material limitations (see Soils section). Typically, elevations are between 7,000 and 8,800 feet (2 135 and 2 680 m) and exposures are northwest- to east-facing. Where sites are protected, however, the phase is encountered at elevations as low as 6,000 feet (1 830 m), or more westerly and southerly exposures. The predominant terrain is moderate to steep, middle and upper slopes.

In addition to the other seral associates, *Pseudotsuga* is normally a major component of seral stands. It often persists as fairly massive individuals in old-growth stands, but it only occasionally establishes in the larger canopy openings. Successional development is similar to that of the ABLA/BERE h.t., PSME phase, although it normally progresses more rapidly, particularly through a *Populus* sere.

Undergrowth is more shrubby in this phase. In addition to *Pachistima*, it usually includes the shrubs *Amelanchier alnifolia, Berberis repens, Rosa* spp., and *Symphoricarpos oreophilus. Aquilegia coerulea* and *Thalictrum fendleri* are often represented with the typal herbs, and *Carex geyeri* is sometimes abundant at lower elevations.

Pedicularis racemosa **(PERA) phase.**—The widespread PERA phase represents the cooler and moister extent of the type. Elevations range from 7,300 feet (2 225 m) to 8,700 feet (2 650 m), but reach up to about 9,600 feet (2 925 m) in the southern Wasatch and Uintas. Most slopes are gentle to moderate on northwest- to southeast-facing uplands and broad ridges. As with the PSME phase, however, the PERA phase occurs on other

exposures on protected sites. Undergrowth is as described for the type.

When present, *Pinus contorta* and *Picea engelmannii* are important seral species. *Picea* is especially pronounced on the most moderate, gentle sites where, as long-lived, large individuals, it typically dominates old-growth stands. *Populus* is less common in this phase; however, on some gentle sites it is an important pioneer species providing a "nurse" cover for subsequent conifer establishment (Daniel and others 1979). Normally short-lived, *Populus* can persist as suckers in smaller canopy openings of old-growth stands. Throughout the phase, the development of a typically dense *Abies* component normally progresses more rapidly than in the PSME phase. Occasionally, *Abies* is the only stand component. Stand structure and developmental processes have been discussed recently by Schimpf and others (1980).

Soils/climate.—For both phases, our stands have surface soils that are predominantly loamy to clayey in texture (appendix D-1). Gravel is often present, and the amount of exposed rock and soil vary considerably. The average litter depth is less in the PSME phase (1.7 inches [4.3 cm]) than in the PERA phase (2.4 inches [6.2 cm]), and averages 2.1 inches (5.3 cm).

The associated geology of the ABLA/PERA h.t. is especially noteworthy. Although a variety of parent materials are represented (appendix D-1), quartzite and other quartziferous and shaley materials predominate; wholly calcareous materials occur infrequently. A few sites occupy glacier-related features. This type, and especially the PERA phase, is largely associated with the quartzite-shaley Wasatch Conglomerate (the Knight formation), a major high- to midelevational formation in the Wasatch Range of northern Utah. Conversely, *Pseudotsuga*, as a major stand component, is encountered less frequently with this formation.

Weather data of the College Forest Station (appendix D-2), situated in an adjacent meadow area, reflects the relative climate of a moderate site in the PERA phase.

Productivity/management.—The ABLA/PERA h.t. generally presents some of the best opportunities for timber management in the northwestern region. The moderate to high productivity in both phases (appendix E) and generally excellent terrain conditions, particularly in the PERA phase, contribute to this. In addition, all species often have massive dimensions in old-growth stands; some trees are the largest we encountered in northern Utah and adjacent Idaho. Regeneration measures range from those creating conditions of partial shade and mineral soil for the more shade-tolerant species, to clearcutting and planting for *Pinus contorta*. Nevertheless, adverse seedling environments for all species might result from clearcutting. Fir broom rust is sometimes particularly troublesome. Bark beetles are also a problem in the Uintas.

The ABLA/PERA h.t. is important summer range for big game. Sheep occasionally use the PERA phase. Seral stands are used more for forage.

Other studies.—Steele and others (1983) have described this habitat type in eastern Idaho and western Wyoming, although their treatment is conceptually narrower. ABLA/PERA has not been mentioned elsewhere.

The ABLA/PERA h.t. is recognized as a much broader concept than that which was previously described (Henderson and others 1976). As such, it includes the more mesic portions of several preliminary types, largely ABLA/*Lathyrus leucanthus*, ABLA/*Arnica latifolia*, ABLA/BERE, and ABLA/OSCH. It excludes, however, exposed sites where *Pinus flexilis* is a dominant stand component or cooler sites where *Ribes montigenum* is present. These sites are now classified as the PIFL phase of the ABLA/BERE h.t., or the RIMO phase of the ABLA/RIMO h.t.

ABIES LASIOCARPA/BERBERIS REPENS H.T. (ABLA/BERE; SUBALPINE FIR/OREGONGRAPE)

Distribution.—ABLA/BERE is the most ubiquitous habitat type of northern Utah and adjacent Idaho (fig. 17). With six phases, it is represented by a total of 214 sample stands (appendix A). ABLA/BERE was first described throughout Utah by Pfister (1972), who recognized only three phases.

Throughout the area, the ABLA/BERE h.t. occupies the relatively cooler and drier exposures of the series. The soils of this type are relatively well drained, and sometimes quite shallow and rocky. Elevations range from about 6,100 to 9,900 feet (1 860 to 3 020 m) in the northwestern region, and from about 7,700 to 10,300 feet (2 345 to 3 140 m) in the Uinta Mountains. Topography is variable, but gentle or undulate terrain and moderate to steep slopes predominate. In a sense the ABLA/BERE h.t. can be considered to be the nucleus of the forested landscape in northern Utah and adjacent Idaho.

Each of the six phases reflects rather specific regimes of the overall environmental span of the habitat type;

Figure 17. The *Abies lasiocarpa/Berberis repens* h.t. is the most widespread coniferous forest type in northern Utah. This stand representing the *Ribes montigenum* phase occurs on a gentle easterly exposure at 9,000 feet (2 740 m) elevation on the Wasatch-Cache National Forest; *B. repens* and widely dispersed clumps of *R. montigenum* typify the depauperate undergrowth.

each is also characterized by certain geologic relationships and management considerations. Table 5 summarizes elevational ranges and exposures by phase in the geographic regions. Site characteristics and pertinent aspects of the associated diverse geology (appendix D) are discussed more specifically under the phase descriptions.

The more south-central areas of the Uinta Mountains, roughly between the Duchesne and Whiterock Rivers, present a special situation. There, sites that are particularly exposed are best considered as the ABLA/JUCO h.t. Such sites typically occupy southerly, steep ridges and slopes, and have exceptionally well-drained soils. In addition, most are associated with the Duchesne formation, a fluvial sandstone consisting of quartzite fragments. This applies especially to stands that are dominated by *Pinus contorta* where replacement by *Abies* is indicated, but is exceptionally slow; these situations are treated as the PICO/JUCO c.t. Thus, only the most moderate sites in the south-central Uinta Mountains are classified as the ABLA/BERE h.t., and then usually as the PSME phase.

Vegetation.—*Abies lasiocarpa* is the indicated climax. It also is sometimes a major pioneer species, especially on the more favorable sites. Typically, late seral stands on favorable sites have a distinct multistoried component of *Abies*; frequently the lower branches of the *Abies* are layered. The structural and successional patterns within the type are essentially as described for the series. Many seral species are associated with the habitat type (appendix B). The occurrence and significance of the major seral associates are discussed for each phase, particularly with respect to the stand conditions.

Several shrubs characterize the typical undergrowth, of which the low, evergreen *Berberis* and *Pachistima myrsinites* are the most indicative. In general, *Berberis* is commonly encountered with the somewhat warmer or drier sites within the type; *Pachistima* has its greatest representation on the slightly cooler exposures. *Symphoricarpos oreophilus* and *Rosa nutkana* (or at lower elevations, *R. woodsii*) are also found throughout the type, as is *Juniperus communis* in the Uintas. Although *Pachistima* has a high constancy overall, Pfister (1972) did not use it to name the type ". . . because of possible confusion with a northern Idaho *Abies lasiocarpa/Pachistima myrsinites* h.t. which is very different floristically (Daubenmire and Daubenmire 1968)."

Although a multitude of herbs are encountered in the habitat type, including many weedy, accidental species, most are only casual in occurrence (appendix C). In general, species diversity is greatest on the most unfavorable exposures and on the moistest sites. Seral stands of *Populus tremuloides* or stands disturbed by livestock have particularly high diversity. On the other hand, seral stands with especially dense canopies and deep duff are usually quite depauperate. Some of the more common undergrowth members include *Achillea millefolium, Aquilegia coerulea, Arnica cordifolia, Pyrola secunda, Stellaria jamesiana, Thalictrum fendleri*, and *Carex rossii*. In the northwestern region, *Aster engelmannii* and *Osmorhiza* spp. are usually present also. Species of *Lathyrus* are locally abundant throughout.

***Pinus flexilis* (PIFL) phase.**—This phase, where *P. flexilis* is a major associate that persists in late seral stands, occurs throughout the northwestern region but is most common in the Wasatch Range of Utah and Idaho. It is also encountered in the geologically complex westernmost Uinta Mountains. But stands in the more eastern Uintas that meet the phasal criterion are typically isolated, local situations within the JUCO phase, such as limestone outcrops along ridge slopes.

Table 5.—Distribution of ABLA/BERE h.t. in northern Utah by phase and geographic region

Phase	Northwestern Utah[1]		Uinta Mountains	
	Elevation range	Exposure	Elevation range	Exposure
	Feet (m)		*Feet (m)*	
PIFL	7,200-9,500+ (2 195-2 895)	SW-N,E	near 10,000 (3 050)	SW-W
RIMO	6,600-9,900 (2 010-3 020)	W-NE-S	8,500-10,100 (2 590-3 080)	W-NE-S
CAGE	6,800-7,700 (2 075-2 345)	W-NE	7,700-9,100 (2 345-2 775)	W-NE-S
JUCO	—		8,300-10,000 (2 530-3 050)	ALL
PSME	6,100-8,800 (1 860-2 680)	ALL	7,700-10,300 (2 345-3 140)	W-NE-S
BERE	6,900-8,600 (2 105-2 620)	ALL	7,800-9,900 (2 375-3 020)	W-N-SE

[1]Includes adjacent Idaho.

Exposures are the most severe of the *Abies lasiocarpa* series (table 5), such as westerly slopes, ridgetops, and isolated knolls of high-elevation sink-basin topography. Substrates are shallow and rocky, calcareous or mixed quartziferous materials, which are often exposed at the surface. Snowpack retention is relatively short, and available soil moisture is low. Furthermore, constant wind augments physiological stress.

Stands occur as isolated groups of trees on particularly severe exposures. Elsewhere stands are somewhat more closed. Typically present are several fairly massive, long-lived *Pinus flexilis*. *Pseudotsuga* is usually present, except in the Uintas on noncalcareous substrates. More local components are variable (appendix B). Of these, *Picea engelmannii*, like *Abies* on extreme sites, slowly establishes on protected microsites near tree bases. A fairly typical, rather lengthy process of stand establishment in a burn area of the Raft River Mountains of Utah that corresponds to this phase has been recently described by Lanner and Vander Wall (1980), which identifies the role of the Clark's nutcracker in *P. flexilis* regeneration.

Undergrowth is generally compositionally diverse and often includes a few especially well-represented species (appendix C). In addition to the typal species, it usually reflects both that of nearby *Symphoricarpos*-dominated shrub communities as well as that of other phases or habitat types of more protected downslope or leeward exposures. At higher elevations, *Ribes montigenum* and *Juniperus* are especially prevalent. The presence of *Shepherdia canadensis* and *Ribes cereum* suggests a rather frequent incidence of light surface fires.

Ribes montigenum **(RIMO) phase.**—As the coolest part of the habitat type, the RIMO phase represents the broad transition or intergrade between the ABLA/BERE and the yet cooler ABLA/RIMO h.t. (Pfister 1972). It is fairly common throughout northern Utah and adjacent Idaho (appendix A). It principally occupies gentle to moderate terrain above 8,000 feet (2 440 m) elevation, or, in the Uintas, above about 9,200 feet (2 805 m) elevation. It also occurs on lower sites that are particularly cool, such as steep, northerly slopes. Substrates vary widely (appendix D).

The principal seral associates are *Picea engelmannii* and, in the northwestern region, *Pseudotsuga*, which is mainly associated with calcareous-dominated substrates and lower elevations. *Populus*, common in the Uinta Mountains, is a major early seral species of easterly or southerly exposures throughout both regions. *Pinus contorta* is infrequent. Stand conditions are fairly similar overall to the THFE and RIMO phases of the ABLA/RIMO h.t. Normal successional development is rather similar to the PIFL and BERE phases, except that *Picea* has its greatest significance here. Interestingly, layered *Abies* was encountered infrequently in our sample stands; no explanation is apparent.

Undergrowth varies from rather depauperate to rather luxuriant. *Arnica latifolia*, *Pedicularis racemosa*, and *Lathyrus* often contribute substantially to the undergrowth. For the most part, *Ribes* occurs as widely scattered clumps near the base of trees. Several additional species are noteworthy in the Uintas: *Astragalus miser*,[4] *Erigeron* spp., *Lupinus argenteus*, *Agropyron trachycaulum*, *Trisetum spicatum*, and with recent fire, *Shepherdia canadensis*.

Adjacent cooler habitat types include ABLA/RIMO, ABLA/VACA, and ABLA/VASC. Nearby warmer sites vary and range from the ABLA/PERA h.t. to other phases of ABLA/BERE, and nonforest communities.

Carex geyeri **(CAGE) phase.**—This phase, however, is common only in the northwestern and southeastern Uinta Mountains. It occupies relatively warm and dry, well-drained, gentle to moderately steep slopes, which reflect the lower extent of the *Abies lasiocarpa* series in these areas (table 5). In the southeastern area, stands of the PICO/BERE c.t. that are dominated by *Carex geyeri* are frequently nearby indicating yet drier conditions. The warmer PSME/BERE h.t., CAGE phase, may also occur nearby. Proximate cooler sites are typically the JUCO phase or occasionally the ABLA/VASC h.t., CAGE phase. Parent materials are diverse (appendix D).

Pinus contorta and *Populus* are the principal seral associates; *Picea pungens* and *Pseudotsuga* are regional associates. Normal succession is prolonged at the dry extent of the phase where *Picea engelmannii* is normally absent. Undergrowth is characterized by a typically abundant cover of *Carex*. *Juniperus communis*, *Astragalus miser*, *Galium boreale*, *Viola adunca*, and *Bromus ciliatus* are sometimes present with the typal species.

The CAGE phase is only rarely encountered in northwestern Utah and adjacent Idaho, where it occupies steep lower slopes (table 5). For management purposes these sites could be considered the PSME phase.

Juniperus communis **(JUCO) phase.**—The JUCO phase is found locally through the northern, southeastern, and southwesternmost Uinta Mountains. It occupies gentle to moderate slopes and benches (table 5). Exposures appear to be influenced by cold air drainage, but are intermediate in dryness as indicated by a minor representation of *Carex geyeri*. More moist nearby sites are the BERE phase or, on even cooler sites, the RIMO phase.

The *Abies* component is usually fairly well developed in late seral stands. *Pinus contorta* and *Populus* are the principal seral associates, as is *Picea pungens* locally. *Juniperus*-dominated stands of the PICO/BERE c.t. are often nearby on drier exposures. As a minor species, *Pseudotsuga* is generally associated with calcareous-dominated substrates, where yet warmer exposures are sometimes the PSME/BERE h.t., JUCO phase.

Undergrowth aspect is typically one of patches of *Juniperus* and *Symphoricarpos*. *Galium boreale*, *Bromus ciliatus*, *Trisetum spicatum*, and species of *Antennaria*, *Erigeron*, *Geranium*, and *Potentilla* are often present along with the typal species.

Pseudotsuga menziesii **(PSME) phase.**—This phase is delineated by the occurrence of *Pseudotsuga*.

As the most common component of the forested landscape of the northwestern region (appendix A), the

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[4]Although *A. miser* was not identified in the stands sampled in Idaho, it is known to occur there.

PSME phase is principally associated with the drier portions of lower subalpine slope areas. These sites are relatively warm or have shallow or seasonally dry soil conditions; most are moderate to steep. Although the phase has a rather broad distribution of exposures (table 5), the majority of sites are west- to northeast-facing and between about 7,000 and 8,200 feet (2 135 and 2 500 m) elevation. Parent materials are chiefly calcareous, although other kinds are also represented; the Wasatch Conglomerate, however, is notably uncommon. Most of the more moderate adjacent sites are the PSME phase of the ABLA/PERA h.t., or in Idaho the ABLA/VAGL h.t., particularly with changes to quartzite-dominated substrates.

The PSME phase is neither very common nor locally extensive in the Uinta Mountains. Where it does occur, it reflects the occurrence of calcareous substrates (limestone and calcareous sandstones) within the temperature range of *Pseudotsuga*. It occupies moderate to steep lower canyon sides and ridge faces, and occurs on generally west-facing slopes at lower elevations and east- to south-facing slopes at higher elevations. Adjacent sites are usually the warmer PSME/BERE h.t. or the cooler JUCO phase.

Pseudotsuga is normally the principal seral species and often establishes beneath canopy openings. It often dominates late seral stands, especially on less favorable sites where succession is slower. *Picea engelmannii* is primarily a minor seral associate at higher elevations of the phase. *Pinus contorta* and *Populus* have fairly high constancy in this phase in the Uintas. *Populus* is particularly significant on lower sites in the northwestern region: with major disturbance, *Populus* often perpetuates repletely and can dominate stands for quite some time.

Undergrowth is similar to that described for the type. In addition to the typal species, *Amelanchier alnifolia, Fragaria vesca, Geranium viscosissimum*, and *Mitella stauropetala* are frequently present in the northwestern region, whereas small coverages of *Galium boreale* and *Phacelia sericea* are common in the Uinta Mountains.

***Berberis repens* (BERE) phase.**—This relatively cool, moist phase occurs throughout the northwestern region. It is especially common in the Utah portion of the Wasatch Range. Exposures are chiefly moderate to steep midslopes (table 5). Parent materials are predominantly quartziferous and include the Wasatch Conglomerate. Adjacent, warmer sites are usually the ABLA/OSCH h.t. and nonforest communities, or the PSME phase where the substrate becomes calcareous. Nearby cooler exposures are the RIMO phase or, when moister, the PERA phase of the ABLA/PERA h.t.

The phase is found in the Uintas mostly in the more northwestern and the southeastern areas above 9,000 feet (2 745 m) elevation where the substrates are mainly quartzite. It locally occupies variable but overall gentle terrain (table 5). In the westernmost Uintas, elevations tend to be lower (around 8,000 feet [2 440 m]) and exposures east-facing, moderate lower slopes. Adjacent cooler exposures are the RIMO and JUCO phases, or the ABLA/VASC h.t. Warmer exposures are usually the CAGE phase and nonforest communities, and occasionally the PICO/BERE c.t.

Major seral associates are *Populus tremuloides* in the northwestern region and *Pinus contorta* in the Uintas. *Picea engelmannii* is local throughout the phase but is of major importance only in the northwestern region, where *Abies concolor* is also sometimes represented.

Undergrowth is normally dominated by the typal species. Small amounts of *Hieracium albiflorum* as well as species of *Fragaria* and *Geranium* occur locally with *Amelanchier alnifolia* (northwestern region) and *Antennaria microphylla* (Uintas).

Soils/climate.—Our northwestern stands have soils that are derived from diverse substrates; those of the Uinta Mountains are derived primarily from quartzite substrates (appendix D). Soils are often very gravelly, or shallow and rocky; some others are quite deep. Surface textures range from loamy to clayey in the northwestern region. In the Uintas, however, they are chiefly sandy loams or loams. Other surface characteristics also vary regionally within phases, although surface rock and bare soil are often absent or only slight in amount. Considerable rock is often present in the RIMO, PIFL, and Uinta PSME phases, as is bare soil in the latter two of these. Litter is generally shallower in the Uintas than in the northwestern area.

Weather data of Silver Lake Brighton (appendix D-2) reflects the relative climate of a moderate site in the RIMO phase.

Productivity/management.—Timber productivity varies between the phases (appendix E). Basically, production in the PIFL phase is low because of stand structure. Productivity is largely low to moderate throughout the Uintas and in the entire RIMO phase. The PSME and BERE phases in the northwestern region have primarily moderate to high productivity. In general, *Picea engelmannii* is the most productive species, judging from average sample site index.

With the exception of the PIFL phase, timber management opportunities are generally good wherever exposures are not too severe or other use considerations do not conflict. Management activities are sometimes limited by shallow soils or rockiness. Regeneration measures in the northwestern region on the more moderate sites are similar to those for the ABLA/PERA h.t. In the Uintas, stands having *Pinus contorta* as a major seral associate can usually be regenerated by clearcutting. Elsewhere throughout the northern Utah area, site protection usually is critical, often necessitating the use of a shelterwood. Also, planting is usually quite difficult except on the best sites; special site preparation measures may be required to reduce competition in the CAGE phase.

The ABLA/BERE h.t. is important for watershed protection. It also provides a major part of big game summer range. *Populus* may locally present special opportunities for improvement of big game browse. Domestic livestock use is moderate in seral stands.

Other studies.—The ABLA/BERE h.t. was first described by Pfister (1972). His preliminary treatment for northern Utah was much broader than ours in that it included essentially all of our lower *Abies lasiocarpa* h.t.'s as well as the ABLA/PERA, ABLA/OSCH and part of the ABLA/VAGL h.t.'s. Pfister also utilized

Symphoricarpos and *Rosa nutkana* as additional indicators for the habitat type; we found that the presence of either *Berberis* or *Pachistima* is adequate in northern Utah. The use of only these two species has also eliminated a potential identification problem for the ABLA/OSCH h.t. where *Symphoricarpos* has a high constancy and *Rosa* is occasionally present.

We have expanded Pfister's (1972) three phases to six with the addition of the PIFL, CAGE, and JUCO phases. While we essentially agree with his treatment of the RIMO phase, a major departure exists with his ABLA and BERE phases. The BERE phase was delineated by the presence of *Picea engelmannii*. The PSME phase, delineated similarly by *Pseudotsuga*, has been adopted in order to facilitate a closer correspondence to the treatment of the more moist ABLA/PERA h.t., the other major type of northwestern Utah and adjacent Idaho. This treatment should serve as a more useful ecological, or zonal, differentiation, especially in view of the associated management implications. Thus, the ABLA phase has been dropped. The BERE phase remains the modal phase, as considered by Pfister, although in a somewhat different context.

An ABLA/BERE h.t. with a CAGE phase is recognized in southeastern Idaho and western Wyoming by Steele and others (1983). There, the type is delineated by the criteria that either *Berberis* or *Pachistima* must be present with at least 1 percent and 5 percent cover, respectively. Our treatment is much broader than theirs, and possibly includes some of their other types as extensions into northern Utah. Their *Abies lasiocarpa/Arnica cordifolia* and *Abies lasiocarpa/Carex rossii* h.t.'s, the most probable extensions, do not appear to be fully analogous to possible northern Utah situations, all of which exhibit a closer conceptual correspondence to the nuclear ABLA/BERE h.t. Thus, the broader approach has been adopted.

ABIES LASIOCARPA/RIBES MONTIGENUM H.T. (ABLA/RIMO; SUBALPINE FIR/MOUNTAIN GOOSEBERRY)

Distribution.—The ABLA/RIMO h.t. is very common throughout the higher elevations of northern Utah and adjacent Idaho (appendix A). Sites are cool and relatively moist in the northwestern region as well as in some areas of the westernmost Uinta Mountains. It generally occurs above 7,000 feet (2 410 m) in the northwestern region and above 9,000 feet (2 745 m) in the western Uintas. Throughout most of the Uintas the habitat type reflects cool or cold and relatively dry exposures. Much of the type occurs above 10,500 feet (3 200 m) encompassing the drier portion of the extensive timberline zone; ABLA/RIMO also extends downward to near 10,000 feet (3 050 m) in the south-central Uintas.

The ABLA/RIMO h.t. was originally described from throughout Utah by Pfister (1972). He recognized three phases, of which the THFE and RIMO are present in northern Utah. Two new phases, TRSP and PICO, are identified for the Uintas. Specific site characteristics are discussed for each phase (appendix D).

Vegetation.—In general, each phase exhibits rather distinct structural and successional overstory characteristics. Some stands are comprised wholly of *Abies lasiocarpa*, the indicated climax. More often, however, *Picea engelmannii* is a major associate that is frequently long-lived and persistent. The seral associates *Pinus contorta*, *Pseudotsuga menziesii*, and *Populus tremuloides* are represented at lower elevations only.

Ribes montigenum, which occurs in sunlit patches at the base of trees, and particularly among layered stems, best typifies the undergrowth. Undergrowth conditions are rather uniform, especially when each phase is considered separately. The undergrowth ranges from depauperate to luxuriantly herbaceous.

***Trisetum spicatum* (TRSP) phase.**—This phase represents most of the ABLA/RIMO h.t. in the Uinta Mountains. It occupies the most exposed sites of the upper timberline zone, that is the upper slopes to ridgetops and plateaulike surfaces from about 10,500 feet (3 200 m) to over 11,200 feet (3 415 m) elevation. These exposures are cool, dry, and windswept. Strong insolation during the day and rapid nocturnal cooling result in wide daily ranges of temperature. Soils are derived principally from quartzite and are typically shallow and rocky. In addition, some are subject to freeze-thaw activity at the higher elevations, and include gentle felsenmeer ground and some limited talus. More protected, moderate sites are usually the VASC phase of the ABLA/VASC h.t., whereas yet colder sites are the PIEN/VASC or PIEN/VACA h.t.'s.

Because of the exposed sites, stand structure is invariably open throughout the phase. It usually forms the timberline zone and is chiefly composed of isolated groups of trees, or copses, that are surrounded by meadow communities. Tree growth form changes with increasing elevation from fairly large but slow-growing trees, through smaller and very slow growing, to the final point at tree line of "flagged" growth forms. Above these elevations growth becomes prostrate; this is the krummholz area of the timberline zone. Upper timberline is generally considered to coincide with a mean July temperature of less than 50° F (10° C) (Pfister and others 1977).

Picea engelmannii is a persistent species in most all of the phase. The lower branches of *Abies, and Picea* to a lesser extent, often tend to layer. Stand establishment is very slow following a major disturbance such as fire. Initial establishment is spotty, with new trees establishing outward under the protection of older established stems. *Abies* can be especially dense in older stands under large *Picea*.

Undergrowth composition is variable, largely because of the local occurrence of many meadow and alpine species. Species dispersion is fairly uniform, however, in that it typically follows two distinct patterns. In general, many species common to the moister nearby habitat types are encountered in minor amounts, with *Ribes* under the protective cover of tree crowns and layered stems. These include *Aquilegia coerulea, Arnica cordifolia, A. latifolia, Erigeron peregrinus, Mertensia ciliata, Pedicularis racemosa, Polemonium pulcherrimum, Pyrola secunda, Carex rossii, Trisetum spicatum, Vaccinium caespitosum*, and *V. scoparium*. Between the groups of trees are such forbs as *Achillea millefolium*,

Antennaria spp. (chiefly *A. microphylla*), *Arenaria* spp., low species of *Erigeron*, *Geum rossii*, *Ivesia gordonnii*, *Penstemon whippleanus*, *Sedum lanceolatum*, *Sibbaldia procumbens*, and *Solidago spathulata*; and the graminoids *Carex rossii*, *Festuca ovina*, *Luzula spicata*, *Trisetum spicatum*, and several species of *Poa* (primarily *P. alpina*, *P. canbyi*, *P. cusickii*, and *P. nervosa*). Many of these species are important components of nearby meadow communities, which are discussed by Lewis (1970).

While *Trisetum spicatum* is used to name the phase, the associated stand structure of these exposed sites is also characteristic. This phase may best reflect the largely unsampled timberline zone forests near Salt Lake City, as well as those of the more western mountain ranges.

***Pinus contorta* (PICO) phase.**—This phase occurs only in the south-central Uinta Mountains near 10,300 feet (3 140 m) elevation roughly between the Duchesne and White Rock Rivers. It occupies drier, gentle to moderately steep slopes and ridges. The well-drained soils are derived from Duchesne sandstone and occasionally quartzite. The PICO phase is typically bounded by the warmer and drier ABLA/JUCO h.t., the more moist ABLA/VASC h.t., VASC phase, and the TRSP phase at higher elevations. *Pinus contorta* and *Picea engelmannii* are the major seral associates. Stands are fairly open. Undergrowth is very similar to higher elevation stands of the ABLA/JUCO h.t., with the addition of widely scattered patches of *Ribes*.

***Thalictrum fendleri* (THFE) phase.**—The THFE phase reflects the most mesic extent of the habitat type. Although it occurs throughout the northwestern region, sampled between 7,900 and 9,600 feet (2 410 and 2 925 m) elevation, this phase is most common in the Wasatch Range of Utah. It is also found in the westernmost Uinta Mountains near 9,600 feet (2 925 m). Exposures are chiefly northwest- to southeast-facing on gentle to moderate slopes. Soils are derived from a variety of materials, including metamorphic, sedimentary (calcareous and noncalcareous), and granitic rocks. Surface soils under canopies usually remain moist through the growing season but rapidly become droughty in open conditions.

Old-growth stands are normally fairly closed and develop a rather dense *Abies* component. When present, *Picea engelmannii* is often a long-lived associate that can attain large dimensions. *Populus tremuloides* is occasionally a major pioneer species on warmer exposures.

The undergrowth is typically the most luxuriant of the high-elevation habitat types. In addition to *Thalictrum* and often abundant *Ribes*, it is characterized by *Aquilegia coerulea*, *Aster engelmannii*, *Osmorhiza chilensis*, *O. depauperata*, and *Stellaria jamesiana*; all of which are very common throughout the phase. More local but nevertheless significant in representation are *Aconitum columbianum*, *Arnica cordifolia*, *A. latifolia*, *Erigeron peregrinus*, *E. speciosus*, *Mertensia ciliata*, *Pedicularis racemosa*, *Polemonium foliosissimum*, *P. pulcherrimum*, *Senecio serra*, *Valeriana occidentalis*, and species of *Geranium* and *Lathyrus*. *Symphoricarpos oreophilus* and *Sambucus racemosa* are the only other shrubs that occur rather constantly, as do the graminoids *Bromus* spp., *Carex rossii*, *Elymus glaucus*, and *Poa nervosa*.

***Ribes montigenum* (RIMO) phase.**—This phase occupies northerly upland slopes that are gentle to very steep and rather cold. Sample stands in the northwestern region range in elevation from 7,900 feet (2 410 m) to 9,500 feet (2 895 m); those in the northwestern Uintas are near 10,000 feet (3 050 m). The phase most likely extends much higher in both regions. Substrates are similar to those of the THFE phase, but the soils appear to be better drained, and hence become more droughty earlier in the growing season. The ABLA/VAME h.t. is sometimes nearby, as are types and phases proximate to the THFE phase.

Overstories are similar to the THFE phase, except that stands tend to be more open. Undergrowth varies from very depauperate, with *Pyrola secunda*, *Carex rossii*, moss, and widely scattered *Ribes*, to rather richly herbaceous, with many of the same species that are common to the THFE phase, especially *Arnica latifolia*.

Soils.—As noted for each phase, our stands have soils that are derived from a variety of substrates (appendix D). Some soils are also glacier-related in origin. Surface soils are predominantly sandy loams or loams in the PICO and TRSP phases; textures are more variable in the THFE and RIMO phases, ranging from sandy loam to clayey. Most soils are gravelly, and some are quite shallow. In general, the more open phases have greater amounts of surface rock and bare soil; litter depth is greatest in the THFE and RIMO phases.

Productivity/management.—Timber productivity is essentially low in the TRSP phase, low to moderate in the PICO and RIMO phases, and moderate to high in the THFE phase (appendix E). Timber management opportunities generally are fair only in the THFE phase. *P. engelmannii* is the primary management species. Regeneration is difficult, as Pfister (1973) emphasized:

> Maintenance of a forest cover is essential for natural regeneration, so establishment of *Picea* requires either a selection or shelterwood system. If clearcut, these stands regenerate extremely slowly because the environmental extremes delay natural seedling establishment and make the probabilities of planting success extremely low.

In addition, most advanced reproduction is suppressed *Abies*, so final removal cuts may result in an unproductive stand.

Domestic livestock use is very local, except for much of the TRSP phase where sheep use is periodically high. The habitat type provides cover for big game and watershed protection. Also, esthetics and recreation are usually important considerations—this habitat type is the site of most ski areas in the Wasatch Range.

Other studies.—An ABLA/RIMO h.t. has been described without phases from southern Montana (Pfister and others 1977), central Idaho (Steele and others 1981), and in eastern Idaho and western Wyoming (Steele and others 1983). *Ribes montigenum* is also a major undergrowth component of the *Abies lasiocarpa/Senecio sanguisorboides* h.t. of central New Mexico (Moir and Ludwig 1979).

The preliminary OSCH and ANMI phases presented in Henderson and others (1977) are generally equivalent to the THFE and the PICO or TRSP phases, respectively.

ABIES LASIOCARPA/OSMORHIZA CHILENSIS H.T. (ABLA/OSCH; SUBALPINE FIR/MOUNTAIN SWEETROOT)

Distribution.—The ABLA/OSCH h.t. is found locally in the northwestern region, but is most common in the Bear River Range. It occupies relatively warm exposures and all aspects at elevations of between about 7,000 and 8,800 feet (2 135 and 2 680 m). ABLA/OSCH is associated primarily with the deeper, ostensibly moister depositional soils of moderately steep, lower-to-middle ridge slopes. This habitat type is also to be expected in the extreme western Uinta Mountains and perhaps through the southern Wasatch Range as well.

Vegetation.—*Abies lasiocarpa* is the indicated climax. *Populus tremuloides* is the major component of seral stands, and *Picea engelmannii* is uncommon. *Pseudotsuga* is usually absent; if present in substantial amounts, the site should be considered to be the ABLA/BERE h.t., with the *Berberis* and/or *Pachistima* absent because of past severe disturbance.

The typical sere begins with a "nurse" cover of *Populus*. Conifer establishment is normally cyclic and spotty except on the most protected sites. Our data show, for example, that the difference in breast-height ages between *Populus* and conifers generally ranges from 10 to 20 years on more protected, northerly exposures, and up to 40 to 50 years or even 80+ years on southerly exposures. Conifer stem density follows a similar pattern. The factors controlling this differential rate of conifer establishment are unclear, but several possibilities have become apparent during this study.

Speculatively, the shade provided by *Populus* ameliorates the physiological stress of new seedlings, particularly on the drier exposures. Soil water in the upper soil profile is rapidly depleted by *Populus* and the typically lush undergrowth vegetation. This serves to limit conifer establishment to the most favorable periods of climatic conditions. Once the conifer roots penetrate the deeper and more moist soil profile, growth rapidly improves. Development to a state of virtual dominance by *Abies* progresses very slowly on unfavorable exposures.

Major site disturbances are fairly common. The significance of fire as a factor for the continual maintenance of *Populus* stands by stimulating suckering, as well as that of major aspen mortality due to various biological agents including large mammals, has been well documented (Krebill 1972; Loope and Gruell 1973; Gruell and Loope 1974; Schier 1975; Hinds 1976). The particularly destructive effect of heavy foraging by deer and livestock on *Populus* regeneration has been addressed by Smith and others (1972) and Mueggler and Bartos (1977). Much of the upper elevation forest land of the Bear River Range burned during the intensive logging and sheep grazing activities of the early 1900's. This created many new *Populus* stands, particularly in this habitat type. Sheep grazing probably also created trampled and compacted soil conditions poor for early conifer establishment, augmenting further the effect of unfavorable exposures.

Two other disturbances are perhaps locally significant in *Populus* maintenance, especially in decadent stands. First, heavy snows may break up foliated canopies. Second, severe winds may "level" stands. With regard to the latter, many ABLA/OSCH sites occupy east-west oriented, flanking ridges and slopes that are downslope from major ridge systems. Such situations are normally not subject to continuous wind (Alexander 1974); but because of this, the infrequent severe winds of short duration would be especially destructive. All of these disturbances except fire would at least temporarily release recently established conifers. Any significant, subsequent *Populus* development would temporarily retard conifer establishment through reinitiated competition.

Undergrowth is principally herbaceous and often includes many weedy species. In addition to the joint indicators *Osmorhiza chilensis* and *O. depauperata*, the most frequently encountered forbs include *Achillea millefolium, Agastache urticifolia, Aquilegia coerulea, Aster engelmannii, Senecio serra*, and *Thalictrum fendleri*. Various graminoids are common, such as *Elymus glaucus* and species of *Agropyron, Bromus, Carex*, and *Poa*. On sites that have been disturbed by livestock, *Lathyrus* spp., *Rudbeckia occidentalis*, and *Stellaria jamesiana* are often abundant. The most significant shrubs are *Symphoricarpos oreophilus* and *Sambucus racemosa*.

Adjacent, warmer sites are usually *Populus*-dominated stands having essentially similar undergrowths. *Symphoricarpos* becomes increasingly important on drier sites, many of which appear to be "stable" *Populus/Symphoricarpos* communities, in the sense of Mueggler (1976). Nonforest communities are sometimes adjacent. Nearby, more mesic habitat types include ABLA/BERE and ABLA/PERA.

Soils.—Our stands are associated primarily with mixed quartziferous substrates (appendix D). Of the latter, the Wasatch Conglomerate and glacial till are especially noteworthy. Surface textures are mainly loamy to clayey. Small gravel fragments are often abundant in the usually deep profile, but exposed rock is nominal. Bare soil is absent or scarce, unless livestock use is high. Litter depth averages 0.9 inches (2.3 cm).

Productivity/management.—The ABLA/OSCH h.t. provides abundant forage for both domestic livestock and big game. Opportunities for improving game forage by maintaining *Populus* are typically very good (Patten and Jones 1976; Schier and Smith 1979). Pocket gopher activity is usually conspicuous, perhaps also influencing conifer establishment.

Although yield capability is moderate to high (appendix E), actual conifer productivity is quite low because of the preponderance of *Populus* and slow successional development.

Other studies.—Steele and others (1981, 1983) have recognized an ABLA/OSCH h.t. from the southern Sawtooth National Forest of Idaho, and eastern Idaho and western Wyoming. Their treatment is conceptually much broader than ours for northern Utah. It largely

corresponds to our ABLA/BERE h.t., and to a lesser extent our ABLA/PERA h.t.

The present treatment of ABLA/OSCH represents a much narrower concept than that which was originally described in Henderson and others (1976). The cooler or drier portions of their type are presently classified in the ABLA/PERA, ABLA/BERE, or ABLA/RIMO h.t.'s.

ABIES LASIOCARPA/JUNIPERUS COMMUNIS H.T. (ABLA/JUCO; SUBALPINE FIR/COMMON JUNIPER)

Distribution.—The ABLA/JUCO h.t. is found only in the south-central Uinta Mountains, roughly between the Duchesne and Whiterocks Rivers, where it is fairly common. Relatively warm and dry, it embraces moderate to very steep ridge and canyon slopes as well as gentle upland surfaces. Elevations are between about 8,700 and 10,500 feet (2 650 and 3 200 m). These sites are typically the most droughty of the *Abies lasiocarpa* series.

Vegetation.—*Abies lasiocarpa* usually is the indicated climax. *Picea engelmannii, Pinus contorta*, and locally *Pseudotsuga menziesii* are seral dominants. *Populus tremuloides* is occasionally a minor seral associate. Stands are fairly open, and replacement progresses rather slowly.

Dense to scattered *Juniperus* accents a rather scant undergrowth, which reflects greatly the dryness of sites. Of the herbs having the highest constancy, *Lupinus argenteus* usually has the greatest abundance. Other, relatively inconspicuous members include *Antennaria microphylla, Arnica cordifolia, Epilobium angustifolium, Fragaria virginiana, Solidago* spp., *Carex rossii, Poa nervosa*, and *Trisetum spicatum*. *Shepherdia canadensis* is occasionally abundant, emphasizing the importance of fire in the type. Minor amounts of *Vaccinium caespitosum* or *V. scoparium* are sometimes present on upland sites; these reflect the proximate, more mesic ABLA/VACA or ABLA/VASC h.t.'s. More xeric slopes are normally the PICO/JUCO c.t.

Soils.—The soils of our stands are derived predominantly from the fluvial sandstone of the Duchesne formation (appendix D). Surface soils are gravelly sandy loams that are typically well drained. Generally, surface rock is present in moderate to considerable amounts, but there is very little exposed soil. Litter averages 1.1 inches (2.9 cm) in depth.

Productivity/management.—Timber productivity is low (appendix E). Because sites are particularly droughty and often steep, opportunities for timber management are few. Forage production is light and wildlife use varies.

Other studies.—An ABLA/JUCO h.t. has been decribed from Montana and Idaho (Pfister and others 1977; Steele and others 1981, 1983), as well as northern Arizona and New Mexico (Moir and Ludwig 1979). In addition, parts of our ABLA/JUCO h.t. appear to be very similar to the *Abies lasiocarpa/Arnica cordifolia* h.t. of eastern Idaho and western Wyoming described by Steele and others (1983).

Pinus contorta Series

Distribution.—The lands that comprise this series support essentially pure stands of *Pinus contorta*, and lack sufficient evidence that another species is the potential climax (Pfister and others 1977). This series occurs in Utah only in the Uinta Mountains. (*Pinus contorta* stands of the northern Wasatch Range should be considered as seral communities of various *Abies lasiocarpa* h.t.'s).

The *P. contorta* series throughout most of the Uintas occupies an elevational belt about 1,500 feet (455 m) in width. In some locations, and most notably in the north-central and northeastern areas, the series is actually a separate zone having *Pinus* as the indicated climax. Varying in altitude, the belt has a minimum lower occurrence at about 7,600 feet (2 315 m) in the western and northeastern areas, and a maximum upper one at about 10,300 feet (3 140 m) in the north-central area. The topography encompassed by the series ranges from gentle or undulate terrain to very steep canyon and ridge slopes; these conditions are typical of the northern and southern Uintas, respectively. Exposures are relatively warm and usually quite droughty with well-drained or shallow soils. On the other hand, some sites have seasonally moist soils, such as those of the PICO/CACA c.t. Environmentally, then, this series reflects or borders on the cold, upper portion of the *Pinus ponderosa* series, the dry portion of the *Pseudotsuga menziesii* series, or the warm, dry portions of the *Abies lasiocarpa* and *Picea engelmannii* series.

Vegetation.—The various factors that may be responsible for complete or near-complete dominance by *P. contorta* are discussed under each type.

The *P. contorta* sample stands were initially grouped by community type for the analysis. Usually, the successional role of *P. contorta*, as defined by Pfister and Daubenmire (1975), was readily discernible for any given stand. Groups or individual stands where the species had a generally "dominant seral" role were placed in the appropriate climax series and habitat type. These included all stands of the northwestern region. Two additional situations, though not specifically sampled, were anticipated and have been included in the *Picea engelmannii* series key.

The remaining groups forming the series had *P. contorta* represented as at least a "persistent seral" species. Of these groups, two had definitive conditions to the extent that *P. contorta* was the indicated climax, not because of any direct, interspecific competitive relationships, but rather because of the severity of the sites. These were designated as habitat types. For purpose of discussion, these were not separated from the community type group. The remaining five groups had more variable conditions and were maintained as community types (c.t.'s). About one-half of these stands had sufficient representation of other conifers (*Abies lasiocarpa, Picea engelmannii*, or occasionally *Pseudotsuga*) and also corresponding site characteristics to indicate that they were persistent seral communities of various habitat types of other series.

Identifying the habitat type of some sites may be particularly difficult in the field, especially those with exceptionally dense stands. Proper placement often can be determined by the investigator through an examination of nearby, more open or older stands occupying similar sites.

Soils.—Soils are derived almost exclusively from quartzite or other quartziferous materials (appendix D). In general, they vary from shallow, when over fractured quartzite bedrock, to rather deep, when associated with various depositional features or certain geologic surface formations. With the exception of some especially moist, clayey soils that occur most notably with the PICO/CACA c.t., soils are typically gravelly and well-drained and have sandy loam or loam surface textures. Many are very droughty. The amount of exposed rock varies, but bare soil is generally absent. Litter usually averages about 1.2 inches (3.0 cm) in depth.

Productivity/management.—Although timber productivity is low throughout the series (appendix E), opportunities for intensive timber management are generally good. The values shown in appendix E may be low because site-index values were not corrected for excessive crown competition. *Pinus contorta* is almost invariably the only conifer having management possibilities. With the exception of the more xeric sites where shelterwood techniques are perhaps more applicable, *Pinus* usually regenerates well with clearcutting and minimal mineral soil preparation (Tackle 1956); in fact, overstocked conditions often occur. Planting, while feasible, ordinarily is not necessary. General silvicultural guidelines have been discussed by Lotan (1975a) and by Alexander (1974), who also considered windthrow hazard, an often critical concern in the Uintas. Three other pertinent regeneration and management considerations for this area are overstocking, the predominant cone habit, and various pest problems. These concerns are present throughout the study area.

Too much regeneration is especially undesirable because at excessive densities *Pinus* is particularly susceptible to early suppression of height and diameter growth. This is perhaps a greater problem with the "better" sites (Alexander 1974). Dense stands of the PICO/CACA c.t. near East Park Reservoir were associated with seasonally moist soil conditions attributed to the presence of an argillic horizon (personal communication with Dennis Austin, Utah Division of Wildlife Resources, Logan). Management for this problem is best considered during the regenerative period. Observations of recent thinning plots on the PICO/CARO h.t., in which acceptable numbers of *Pinus* seedlings became established under various thinning regimes, indicate that shelterwood cuttings might substantially alleviate overstocking on local areas. In the same area, overcrowding was less on recent clearcuts that had received heavy cattle use. Several of these had been additionally seeded to forage species, perhaps further increasing regeneration-vegetation competition and reducing stocking. Minimum levels of site preparation also may be useful in certain instances.

The predominant cone serotiny habit of *Pinus* is especially important because it largely determines the appropriate site and slash preparation measures for regeneration (Lotan 1975a). As a part of a broad regional study to identify general serotiny patterns of the species, Lotan (1975b) sampled several *Pinus* stands in the northern and eastern Uinta Mountains. He found that the percentage of serotinous cones of his sample stands in the Uintas was rather uniform within stands but quite variable between stands. The predominant cone habit was that of nonserotiny. In the Ashley National Forest samples, he also found that an increase in serotiny was correlated with increasing elevation ($r^2 = 0.468$). We also observed these general relationships; furthermore, we observed that the predominant cone habit throughout northern Utah appeared to be nonserotinous. In most situations, therefore, sufficient seed should be present in adjacent stands to regenerate clearcuts. And as a general rule, Lotan (1975b) suggested a maximum cutting width of about 200 feet (60 m) to insure adequate seed dispersal.

In northern Utah, *Pinus* is affected by several diseases and pests. Currently, the most serious problem is dwarf mistletoe (*Arceuthobium americanum*). This parasite is responsible for a significant reduction of potential growth and mortality (Hutchinson and others 1965). Local partial-cutting practices ("high-grading" or "tie-hacking") prior to 1900 in infected stands of the more western, northern areas directly resulted in an intensification of today's problem. For example, Hutchison and others (1965) reported that 55 percent of the *P. contorta* cover type in those areas had at least a 10 percent infection rate. To facilitate a tentative identification of distributional relationships, the presence of dwarf mistletoe was included as part of our plot examination in the Uintas. Infected trees were noted on 25 plots at elevations of between 8,600 and 10,300 feet (2 620 and 3 140 m). Of the 10 types having observed infections, the most frequent were the PICO/ARUV h.t., the ABLA/VASC h.t., CAGE and VASC phases, and the PICO/VACA c.t. Others were the PICO/VASC and PICO/BERE c.t.'s and the ABLA/CACA, ABLA/VACA, ABLA/BERE (CAGE phase), PIEN/VACA, and PIEN/VASC h.t.'s. Interestingly, dwarf mistletoe was rarely observed in the southwestern and south-central areas.

Throughout northern Utah, comandra blister rust (*Cronartium commandrae*) and western gall rust (*Endocronartium harknessii*) are locally responsible for reduced vigor and growth as well as direct, but more limited mortality. Various root and stem decays are even more harmful; these pathogens often account for appreciable losses in merchantability and mortality in old-growth stands (Krebill 1975).

Insects and animals can also cause considerable damage. Past epidemics of the mountain pine beetle (*Dendroctonus ponderosae*) resulted in extensive mortality throughout much of the northern area (Hutchinson and others 1965). Currently, damage is localized; eruptions of the pest can certainly occur in the future,

however. The most significant mammal pests are pocket gophers and porcupines; the latter are especially harmful in managed stands in the Wasatch Range (Daniel and Barnes 1959).

Nontimber values of the *Pinus contorta* series are diverse. Utilization by various wildlife species has been studied locally by Collins and others (1978), Deschamp and others (1979), and Winn (1976). The effect of management activities on water yield and quality is an important consideration throughout. Domestic livestock use is associated with sites where forage areas are proximate.

Other studies.—Various, often similar *Pinus contorta* community types have been described from Montana (Pfister and others 1977), central Idaho (Steele and others 1981), and eastern Idaho, western Wyoming (Cooper 1975, Steele and others 1983).

Pfister and Daubenmire (1975) listed the current references to plant communities in the northwestern United States which refer to *P. contorta* as climax. Several specific situations are particularly noteworthy. Cooper (1975) and Pfister and others (1977) recognized a *Pinus contorta/Purshia tridentata* h.t. in southwestern Montana. In central Idaho, a *Pinus contorta/Festuca idahoensis* h.t. has been described by Steele and others (1981). Hoffman and Alexander (1976) and Reed (1976) recognized a total of three PICO habitat types in Wyoming. Also, Moir (1969) discussed a zone in the Colorado Front Range where *P. contorta* is either a prolonged seral species or climax. This zone is similar in several respects to the *P. contorta* series of the Uinta Mountains, as is the climax zone of the Bighorn Mountains, Wyoming (Despain 1973).

PINUS CONTORTA/CALAMAGROSTIS CANADENSIS C.T. (PICO/CACA; LODGEPOLE PINE/BLUEJOINT REEDGRASS)

Distribution.—This community type occurs locally in the northern Uinta Mountains and eastward through the southeastern area. Elevations range from about 8,800 feet to 9,800 feet (2 680 to 2 985 m). Most sites occupy gentle slopes that are relatively cool and generally dry. Usually, surface soils are seasonally moist, a condition that apparently results from a local drainage-impeding soil structure (such as an argillic horizon).

Vegetation.—*Populus tremuloides* is occasionally a minor seral species. All sample stands had evidence of past fire occurrence, and only two were older than 150 years of total age. Scattered, stunted reproduction of other conifer species was represented in six stands.

For our sample stands, then, it appears that *Abies lasiocarpa* is the indicated climax and that *Pinus* is a persistent seral species. *Picea engelmannii* is locally present as a seral associate. Sites are somewhat drier than, but generally as cool as, the ABLA/CACA h.t. The possible role of fire in removing on-site, shade-tolerant seed sources is more pronounced in the PICO/CACA c.t. than elsewhere in the series. This is because many adjacent drier sites are the PICO/VACA or PICO/VASC h.t.'s that are normally without any representation of other conifers.

Calamagrostis creates the dominant aspect of the undergrowth, although *Vaccinium caespitosum* is sometimes also abundant, reflecting the relative coolness of a site. The other common shrubs and herbs (appendix C) represent a rather intermediate floristic transition between the wetter ABLA/CACA h.t. and the drier ABLA/VACA or PICO/VACA types.

Soils.—The moist soils of our stands are derived from a variety of quartziferous parent materials (appendix D) and are associated mainly with glacial, alluvial, or other depositional features. Textures range from sandy loam to clayey. Gravel content varies. Exposed soil and rock are generally absent or only slight, although the latter is sometimes present in moderate amounts. Litter averages 1.2 inches (3.0 cm) in depth.

Productivity/management.—Although timber productivity is low to moderate (appendix E), it is generally good, compared to the series as a whole. Clearcutting should provide adequate regeneration of *Pinus* even though some soils may become temporarily waterlogged. Although dense, stagnated stands do occur, diameter growth and thinning from natural competition was exceptionally good in the majority of our sample stands; frost-heaving has perhaps served to thin seedlings during stand establishment.

The PICO/CACA c.t. provides cover and forage for big game species (Winn 1976). Cattle use is also locally high.

Other studies.—PICO/CACA communities occur in Montana (Pfister and others 1977), central Idaho (Steele and others 1981), and northwestern Wyoming and adjacent Idaho (Cooper 1975; Steele and others 1983). These authors, however, did not describe a PICO/CACA c.t.; rather, they considered all stand conditions directly with the ABLA/CACA h.t.

PINUS CONTORTA/VACCINIUM CAESPITOSUM C.T. (PICO/VACA; LODGEPOLE PINE/DWARF HUCKLEBERRY)

Distribution.—Although it is found throughout the Uinta Mountains, the PICO/VACA c.t. is commonest in the northern and eastern areas. It characteristically occupies topography subject to cold air accumulation. Such sites include meadow edges, gentle terrain having depressions, and occasionally steeper slopes. Elevations are between 8,300 feet (2 530 m) and about 10,000 feet (3 050 m). A notable exception is found in the western area where the type occurs on some steep, south-facing sites near 7,700 feet (2 345 m) elevation that have moist substrates.

Vegetation.—*Populus tremuloides* is a local, minor seral species. Other conifers were absent in many of our sample stands and replacement by shade-tolerant species appeared to be particularly prolonged.

Six stands probably best represented the ABLA/VACA h.t. These had minor amounts of *Abies* and occurred outside the north-central area between 8,300 and 9,700 feet (2 530 and 2 955 m) elevation. This also appeared to be the case for three rather unusually brushy, species-rich stands near 7,700 feet (2 345 m) in the western area, even though *Abies* was absent. Small amounts of *Picea engelmannii* were present in five

higher stands at 9,700 to 10,300 feet (2 955 to 3 050 m) elevation; because the stands were relatively old—more than 150 years—it is uncertain whether they represent persistent seral communities of the PIEN/VACA h.t. or situations of a *P. contorta* climax. Of the 14 remaining stands that lacked other conifers, about eight that occupied relatively dry sites likely reflected a PICO/VACA h.t.: for instance, sites where *Arctostaphylos uva-ursi* was present and the PICO/ARUV h.t. was adjacent.

In addition to *V. caespitosum* and *Juniperus communis*, undergrowth often includes other shrubs that are indicative of nearby, warmer habitat or community types, such as *A. uva-ursi, Berberis repens, Pachistima myrsinites*, or *V. scoparium*. Many herbaceous species are also represented, the most common of which are *Antennaria* spp., *Arnica cordifolia, Fragaria virginiana, Carex rossii, Poa nervosa*, and *Trisetum spicatum*. Furthermore, *Polygonum bistortoides* is a characteristic undergrowth species of sites adjacent to meadow edges.

Soils.—Substrates are dominated by quartzite or other quartziferous materials (appendix D), which are often glacial till. Surface soils range from gravelly sandy loams to moist clays. Bare soil is usually absent, and exposed rock varies from absent to considerable. The average litter depth is 1.2 inches (3.0 cm).

Productivity/management.—Timber productivity is low to moderate (appendix E). *Pinus contorta* usually regenerates well with clearcutting. Following this practice, however, some gentle sites may become temporarily waterlogged. Other uses vary, but habitat values for elk predominate in many areas (Winn 1976).

Other studies.—The PICO/VACA c.t. has been described from Montana by Pfister and others (1977), and from central Idaho by Steele and others (1981). These authors have treated most all of their sample stands as successional communities occupying other habitat types.

Franklin and Dyrness (1973) listed *Pinus contorta/Vaccinium uliginosum* communities from central Oregon that may be related to the moister stands of our PICO/VACA. These communities had *V. caespitosum* as a characteristic component. Also, two of Moir's (1969) "subalpine" stands in the Colorado Front Range included *V. caespitosum* as an undergrowth member. These stands occur at the higher elevations of a zone where *P. contorta* is either a prolonged seral species or climax.

PINUS CONTORTA/VACCINIUM SCOPARIUM C.T. (PICO/VASC; LODGEPOLE PINE/GROUSE WHORTLEBERRY)

Distribution.—PICO/VASC is found throughout the northern and eastern Uinta Mountains between about 8,500 and 10,000 feet (2 590 and 3 050 m) elevation. It occupies gentle upland surfaces and gentle to moderately steep ridge-slopes. In relation to the series as a whole, exposures are relatively cool but dry.

Vegetation.—PICO/VASC communities sampled in the more central areas of the southern Uintas were always recognizable as seral communities of either the PIEN/VASC h.t. or the VASC phase of the ABLA/VASC h.t.; thus, they have been included in those types. Most all of the other stands considered under this category occupied relatively droughty exposures.

Six of our sample stands occupied very dry exposures between about 9,300 and 10,000 feet (2 835 and 3 050 m) elevation, of which four were over 150 years old and two were over 200 years. Five of these six stands also had very widely scattered *Picea engelmannii* of about the same stand age, and some stunted but otherwise similar *Abies lasiocarpa*; the other stand was entirely *Pinus* in composition. Three younger stands also had similar representation of these shade-tolerant conifers.

In terms of a general stand establishment model for the higher elevations, these conditions suggest that most *Picea*, and probably most *Abies*, becomes established with *Pinus*, probably throughout the latter's rather prolonged period of stand establishment. Once the stand develops an extensive, shallow root system and duff further accumulates, however, the seedbed becomes too droughty for any appreciable subsequent establishment of *Picea* or *Abies*. Limiting amounts of critical mineral nutrients may also impede establishment. From a management standpoint, then, sites such as these are probably best considered a *Pinus contorta* climax, with other conifers occurring as accidentals. For the Uintas, both of the above factors are probably more significant than the occurrence of presumably frequent, natural surface fires in curtailing *Picea* and *Abies* regeneration.

Of the nine remaining younger stands, four pure *Pinus* stands occupied very droughty sites at about 9,100 feet (2 775 m) elevation. These sites most certainly represented a PICO/VASC h.t., regardless of stand ages. Stunted *Abies* was present in the other, more mesic samples that occurred near 8,900 feet (2 715 m). Some of these possibly reflected the same stand establishment conditions noted for the higher elevation stands having *Picea*. One eastern stand that had an abundant cover of *Calamagrostis rubescens* was clearly seral to *Abies*.

Usually *V. scoparium* conspicuously dominates the undergrowth. With exceptionally droughty sites, however, this coverage is sometimes very patchy. Some of the more common herbs include *Achillea millefolium, Antennaria microphylla, Arnica cordifolia, Epilobium angustifolium, Lupinus argenteus, Carex rossii, Poa nervosa*, and *Trisetum spicatum*. Several shrubs are often represented, such as *Juniperus communis, Berberis repens, Pachistima myrsinites*, or *V. caespitosum*; the latter three species often reflect nearby habitat or community types.

Soils.—The soils of our sample stands are generally similar to those described for the PICO/VACA c.t. (appendix D). The major exception is that the surface soils are most always gravelly and drier. Litter averages 1.1 inches (2.9 cm) in depth.

Productivity/management.—Timber productivity is low (appendix E). Regeneration is usually successful on small clearcuts, although stand establishment may be prolonged on drier sites. Natural thinning appears to occur readily in most stands.

Nontimber uses are similar to those described for the ABLA/VASC h.t.

Other studies.—Hoffman and Alexander (1976) recognize a PICO/VASC h.t. from the Bighorn Mountains, Wyo. This type is similar in many respects to the drier extent of our stands designated as a *P. contorta* climax. The PICO/VASC c.t. has been described from Montana (Pfister and others 1979), central Idaho (Steele and others 1981), and eastern Idaho, western Wyoming (Steele and others 1983). In Montana, Idaho, and Wyoming, the community type normally occupies the ABLA/VASC h.t., although these authors recognize certain droughty conditions where *P. contorta* may be climax.

PINUS CONTORTA/JUNIPERUS COMMUNIS C.T. (PICO/JUCO; LODGEPOLE PINE/COMMON JUNIPER)

Distribution.—The PICO/JUCO c.t. occurs only in the south-central Uinta Mountains. There, it is found primarily between the Whiterocks River and eastern Duchesne River drainages. It occupies most all southerly, moderately steep to very steep ridge and canyon slopes (east- and west-facing). Elevations are between about 8,400 and 10,000 feet (2 560 and 3 050 m). These exposures are warm and soils are extremely well drained, being some of the driest within that area.

Vegetation.—This community type occurs within the normal altitudinal distribution of *Abies lasiocarpa* or *Pseudotsuga menziesii*; the ABLA/JUCO or PSME/BERE h.t.'s are usually nearby on the more protected exposures. All of our sample stands occupied burn areas that were between 80 and 120 years old. In addition, one two-storied stand included several residual trees of about 250 years of age. Stands were normally quite dense; *Populus tremuloides* was a local pioneer species that had been rapidly shaded out. Eight of the 14 stands had minor representation of *Abies*, *Pseudotsuga*, or *Picea engelmannii*. Replacement by these species appears to be exceptionally slow.

Undergrowth also exhibits the influence of fire. In addition to *Juniperus*, several "fire" shrubs are locally present, such as *Arctostaphylos patula, Amelanchier alnifolia, Rosa* spp., and *Salix scouleriana*. The herbaceous component is typically depauperate. The most frequently encountered species include *Aster glaucodes, Epilobium angustifolium, Bromus ciliatus, Carex rossii*, and species of *Festuca* and *Poa*.

Small amounts of *Berberis repens* and occasionally *Pachistima myrsinites* are encountered in the undergrowth, which suggests that these sites might be a part of the PICO/BERE c.t. With the exception of a few instances, however, the undergrowth and typical topography are more representative overall of the ABLA/JUCO h.t.—a type where these two species are apparently absent. These communities, then, are treated separately from the PICO/BERE c.t., which is elsewhere more similar to the ABLA/BERE h.t. Although the successional status of *Pinus* for the most part is uncertain primarily because of stand ages, *Pinus* can be considered a persistent seral species. Most lower elevation seral stands may best reflect the PSME/BERE h.t., and higher seral stands may represent the ABLA/JUCO h.t. Stands of the very warm and well-drained droughtiest sites might well be a PICO/JUCO h.t.

Soils.—The soils of our stands are chiefly derived from either sandstone of the Duchesne formation, or from Uinta quartzite (appendix D). Stands occupying other substrates, especially calcareous materials, are most likely another habitat type such as PSME/BERE. Surface soils are usually gravelly sandy loams or gravelly loams. Generally considerable rock is exposed, but little or no bare soil. Litter averages 1.1 inches (2.7 cm) in depth.

Productivity/management.—Timber productivity is low to moderate (appendix E). Opportunities for timber management are nominal in most instances because of slope steepness. Wildlife use is mainly as cover.

Other studies.—Steele and others (1981) have described a PICO/JUCO c.t. from central Idaho, which occurs locally eastward through Idaho to adjacent Wyoming (Steele and others 1983). It has been considered to occupy the ABLA/JUCO h.t. or occasionally the PSME/JUCO h.t. In Montana, PICO/JUCO communities have been considered part of the PSME/JUCO h.t.

PINUS CONTORTA/ARCTOSTAPHYLOS UVA-URSI H.T. (PICO/ARUV; LODGEPOLE PINE/BEARBERRY)

Distribution.—This very warm and dry habitat type occurs principally in the northern Uinta Mountains, and is most extensive in the northeastern area. It occurs on gentle upland terrain as well as ridgetops and steeper slopes. Elevations range from 8,200 feet (2 500 m) to 9,500 feet (2 895 m). In the southern Uintas, *A. uva-ursi* usually reflects extreme soil drainage conditions.

Vegetation.—The structure of our sample stands varied from rather dense to more often moderately open. In the latter instance, five stands were more than 200 years old; an additional nine were older than 150 years. *Pinus contorta*, which had a predominantly nonserotinous cone habit, was intermittently self-replacing. Seedling establishment in self-replacing stands possibly coincided with periods of favorable soil moisture that followed a light surface fire of the prior growing season, a situation where seedbed conditions would have been optimal.

Populus tremuloides is a minor seral associate, with local distribution. As accidental species, *Abies lasiocarpa* and *Pseudotsuga menziesii* are normally restricted in occurrence to the moistest microsites.

Patches of *Arctostaphylos*, which often occurs at the base of trees, characterize the undergrowth. Other common species include *Berberis repens, Juniperus communis, Antennaria* spp., *Arnica cordifolia, Astragalus miser, Epilobium angustifolium, Lupinus argenteus, Sedum lanceolatum, Solidago spathulata, Carex rossii*, and *Poa nervosa*.

Nearby more moderate exposures are usually other *P. contorta* habitat types or, with a transition to calcareous parent materials, the PSME/SYOR h.t. or the JUCO phase of the PSME/BERE h.t. The *P. ponderosa* series is sometimes adjacent at lower elevations in the northeastern area where temperatures are sufficiently warm for this species.

Soils.—The droughty well-drained or shallow soils of our stands are derived almost exclusively from quartzite

materials (appendix D). Gravelly sandy loam is the predominant surface soil. Usually, little bare soil but occasionally considerable rock is exposed. Litter is sometimes intermittent, averaging 1.1 inches (2.7 cm) in depth.

Productivity/management.—Timber productivity is the lowest of the series (appendix E). Regeneration by clearcutting is sometimes difficult on poorer sites. Shelterwood techniques may successfully regenerate some poor sites, although dwarf mistletoe infection is often severe.

Deer frequently utilize this habitat type. Cattle use is common wherever forage areas are nearby.

Other studies.—Pfister (1972) briefly described the PICO/ARUV h.t. in the Uinta Mountains. A similar habitat type has been recognized from the Bighorn Mountains, Wyo., by Hoffman and Alexander (1976) and Despain (1973).

Moir (1969) discussed "montane" stands in the Colorado Front Range, which bear striking topographic and floristic similarities to our stands. Franklin and Dyrness (1973) summarize the climax PICO/ARUV communities from various locations in southwestern Washington and northwestern Oregon. A climax PICO/ARUV community also occurs in the pumice region of central Oregon, although it is environmentally unlike the conditions of the Uinta Mountains because of seasonally moist soils (Youngberg and Dahms 1970).

PINUS CONTORTA/BERBERIS REPENS C.T. (PICO/BERE; LODGEPOLE PINE/OREGONGRAPE)

Distribution.—The PICO/BERE c.t. occurs throughout the more north-central and eastern Uinta Mountains (fig. 18). Elevations are between about 7,700 and 10,000 feet (2 345 and 3 050 m). Terrain is fairly similar to that of the PICO/ARUV h.t., although exposures are usually more moderate, being southerly in the more western and southeastern areas but shifting to more northerly in the northeastern area. Many stands of the south-central Uintas with *Berberis* or *Pachistima* should be considered as the much warmer and drier PICO/JUCO c.t.

Vegetation.—*Populus tremuloides* is often a major seral associate. Most of our sample stands appeared to be distinctly even-aged. Several exhibited early stagnation and some were also very dense. All stands occupied recent burns, with only two being older than 150 years total age. It was evident that stand establishment took considerable time on the more droughty sites.

Only two stands were sampled in the westernmost Uinta Mountains. One stand apparently reflected the driest extent of the PSME/BERE h.t., CAGE phase, occupying a gentle southwesterly slope at 8,700 feet (2 650 m) elevation. The other, occupying a steep southwest-facing slope at 8,400 feet (2 560 m) elevation, was unique in several respects. *Abies lasiocarpa* and *Abies concolor* were represented by a few seedlings and saplings, and the undergrowth was dominated strikingly by *Arctostaphylos patula*. Elsewhere, only four stands had minor amounts of *A. lasiocarpa*; these occurred between 7,700 and 9,900 feet (2 345 and 3 020 m) elevation. The remaining 14 stands were comprised entirely of *Pinus* (excluding *Populus*).

Figure 18. *Pinus contorta/Berberis repens* community type near Poison Mountain at 9,840 feet (3 000 m) elevation on the north slope of the Uinta Mountains. The sparse undergrowth is dominated by *Astragalus miser, B. repens*, and *Poa nevadensis*.

Five stands with abundant *Carex geyeri* in the eastern Uintas occupied sites fairly similar to those of the ABLA/BERE h.t., CAGE phase. The other stands occupied sites that are fairly similar to the JUCO and BERE phases of ABLA/BERE h.t. It appears, however, that many stands of the northern Uintas potentially reflect a PICO/BERE h.t. regardless of stand ages. As such, these stands would represent a part of the climax *Pinus contorta* zone occurring throughout that area, the major component of which is the drier and frequently adjacent PICO/ARUV h.t.

The evergreen shrubs *Berberis, Pachistima myrsinites*, and *Juniperus communis* normally characterize a rather sparse undergrowth except when *Carex geyeri* is abundant. Elsewhere, the most conspicuous herbs are *Antennaria microphylla, Arnica cordifolia, Astragalus miser, Lupinus argenteus, Poa nervosa*, and *Carex rossii*. Also, *Vaccinium caespitosum* is occasionally represented in minor amounts, typically reflecting the nearby, cooler PICO/VACA c.t.

Soils.—Our stands have soils that are derived predominantly from quartziferous materials (appendix D). Those of the northern Uintas are quite gravelly and mainly associated with either well-drained till deposits or shallow bedrock. The latter condition is fairly common, with sites occurring on the "Gilbert Peak surface" and similar landforms. All stands of the southeastern Uintas are associated with the Browns Park formation where soils are fairly deep and ostensibly more moist. In general, surface soils are sandy loams. The amount of exposed rock varies, but bare soil is generally absent. Litter averages 1.3 inches (3.2 cm) in depth.

Productivity/management.—Timber productivity is low (appendix E). Clearcuts normally regenerate readily on more mesic exposures. Where regeneration is expected to be profuse, minimum site preparation might help reduce excessive densities. Bark beetle infestations can be especially destructive.

Local ungulate and livestock use is varied throughout the Uintas. Seral stands having *Populus* as a major component are especially important for moose in the north-central area (Winn 1976).

Other studies.—The PICO/BERE c.t. has not been previously described. Steele and others (1983) consider somewhat similar communities to occupy a conceptually narrower ABLA/BERE h.t. Also, a few of our stands are similar overall to their *Pinus contorta/Arnica cordifolia* c.t. of eastern Idaho and western Wyoming.

PINUS CONTORTA/CAREX ROSSII H.T. (PICO/CARO; LODGEPOLE PINE/ROSS SEDGE)

Distribution.—The PICO/CARO h.t. is restricted to the north-central Uinta Mountains where it occurs at elevations of about 9,000 feet (2 745 m) to 9,700 feet (2 955 m). The type occupies the distinctive "Gilbert Peak surface" (Bradley 1964), a broad, gently north-sloping upland terrain, as well as several undifferentiated depositional features (Stokes and Madsen 1961). In comparison to the series as a whole, these sites are relatively intermediate in temperature, moistness, and soil drainage. As such, they apparently reflect a transition between the PICO/BERE and PICO/VACA community types.

Vegetation.—The overstory of all sample stands was entirely *Pinus contorta*. Several stands were dense and stagnated, and only one was open and older than 200 years. Judged solely on the basis of the sample stands, the successional status of *Pinus* was uncertain. Nevertheless, additional observations of typical stand conditions within the immediate area helped identify the climax status of *Pinus* on these sites.

Specifically, *Abies lasiocarpa* and *Picea engelmannii* were usually absent in these areas; when present, however, all age classes including reproduction were restricted to favorable microsites, primarily the better drained slopes. Also, corresponding situations having either of these species as the indicated climax were not identified from either the Uintas or from northern Utah. Consequently these sites probably best reflect a *Pinus contorta* climax, a status that is further supported by the apparent predominant interaction of the prevailing "rain shadow" growing season precipitation patterns and edaphic factors.

Populus tremuloides is normally absent in this habitat type. The sparse undergrowth consists of scattered herbs, the most frequent of which are *Antennaria microphylla, Arnica cordifolia, Astragalus miser, Fragaria virginiana, Geranium* spp., *Lupinus argenteus, Carex rossii, Poa nervosa, Sitanion hystrix*, and *Trisetum spicatum*. Small amounts of the shrubs *Juniperus communis* and *Rosa* spp. are sometimes present as well.

Soils.—The soils of our stands are derived almost exclusively from quartzite materials (appendix D). Soil drainage and depth to bedrock varies locally. In general, surface soils are gravelly sandy loams or gravelly loams, and some rock and bare soil are exposed. Litter averages 1.0 inches (2.5 cm).

Productivity/management.—Timber productivity is low to moderate (appendix E). For the Uinta Mountains as a whole, however, this type presents some of the best, locally extensive opportunities for timber management. Following clearcutting, excessive regeneration of *Pinus* and early stand stagnation are common; normally, some stocking control is necessary. (Because of the effect of excessive density on *Pinus* height growth in our unmanaged sampled stands, some productivity estimates may be artificially low for this type in particular.)

Wildlife habitat values are moderate (Winn 1976). Cattle use is greatest near recent clearcuts.

Other studies.—Steele and others (1983) have recognized a PICO/CARO c.t. from western Wyoming as a seral community type of the high elevation *Pinus albicaulis/Carex rossii* h.t.

The PICO/CARO c.t. is an anomaly insofar as an expected, corresponding ABLA/CARO h.t. has not been identified from the immediate area or from northern Utah. Although an ABLA/CARO h.t. has been recognized in the southern Sawtooth National Forest in Idaho (Steele and others 1981), the correspondence between these types is apparently one of type-name only.

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APPENDIX A. NUMBER OF SAMPLE STANDS BY HABITAT TYPE OR PHASE AND NATIONAL FOREST VICINITY IN NORTHERN UTAH AND ADJACENT IDAHO AND WYOMING

SI = Sawtooth National Forest, Idaho
C = Caribou National Forest, Idaho
SU = Sawtooth National Forest, Utah
WW = Wasatch and Uinta National Forests, NW Utah
U = Uinta National Forest, Idaho NE Utah
WE = Wasatch National Forest, NE Utah, and adjacent Wyoming
A = Ashley National Forest (and Uintah and Ouray Reservation)

Habitat type, phase	National Forest vicinity							
	SI	C	SU	WW	U	WE	A	Total
Pinus flexilis series								
PIFL/CELE	.	3	.	4	.	.	.	7
PIFL/BERE	.	.	.	5	.	.	.	5
								12
Pinus ponderosa series								
PIPO/CAGE	.	.	.	.	.	.	8	8
PIPO/FEID, ARPA	.	.	.	.	.	.	8	8
/FEID, ARTR	.	.	.	.	.	.	6	6
/FEID, FEID	.	.	.	.	.	.	15	15
								37
Pseudotsuga menziesii series								
PSME/PHMA	2	3	.	37	2	.	.	44
PSME/ACGL	2	6	.	7	.	.	2	17
PSME/OSCH	4	8	.	15	.	.	.	27
PSME/CELE	.	3	.	7	.	.	.	10
PSME/CARU	.	1	.	.	.	.	.	1
PSME/SYOR	.	.	.	.	.	1	6	7
PSME/BERE, CAGE	.	1	.	5	2	1	4	13
/BERE, JUCO	.	.	.	.	.	3	8	11
/BERE, SYOR	.	1	.	10	.	.	.	11
/BERE, BERE	.	10	1	17	.	2	9	39
								180
Picea pungens series								
PIPU/AGSP	.	.	.	.	.	.	7	7
PIPU/BERE	.	.	.	.	.	2	7	9
								16
Abies concolor series								
ABCO/PHMA	.	.	.	8	.	.	.	8
ABCO/OSCH	.	.	.	5	.	.	.	5
ABCO/BERE, SYOR	.	.	.	7	.	1	.	8
/BERE, BERE	.	.	.	10	.	1	2	13
								34
Picea engelmannii series								
PIEN/EQAR	.	.	.	2	1	3	.	6
PIEN/CALE	.	.	.	.	.	1	4	5
PIEN/VACA	.	.	.	.	.	3	11	14
PIEN/VASC	.	.	.	.	.	10	7	17
								42

(con.)

Habitat type, phase	National Forest vicinity							
	SI	C	SU	WW	U	WE	A	Total
***Abies lasiocarpa* series**								
ABLA/CACA	.	.	.	.	.	1	4	5
ABLA/STAM	.	.	.	.	.	2	1	3
ABLA/ACRU	.	1	.	9	1	.	.	11
ABLA/PHMA	.	.	.	9	1	.	.	10
ABLA/ACGL	.	12	.	8	.	.	2	22
ABLA/VACA	.	.	.	.	2	4	6	12
ABLA/VAGL	.	18	.	6	2	2	.	28
ABLA/VASC, ARLA	.	3	.	.	1	18	6	28
/VASC, CAGE	.	.	.	.	.	8	1	9
/VASC, VASC	.	.	.	.	1	9	37	47
ABLA/CARU	1	4	1	5	.	.	6	17
ABLA/PERA, PSME	.	18	.	10	2	2	.	32
/PERA, PERA	.	9	.	20	4	1	.	34
ABLA/BERE, PIFL	.	7	.	8	.	4	.	19
/BERE, RIMO	.	16	3	16	8	5	10	58
/BERE, CAGE	.	1	.	2	1	5	8	17
/BERE, JUCO	.	.	.	.	.	5	10	15
/BERE, PSME	2	6	2	51	3	1	8	73
/BERE, BERE	.	2	1	18	1	6	4	32
ABLA/RIMO, TRSP	.	.	.	1	.	4	13	18
/RIMO, PICO	.	.	.	.	.	.	8	8
/RIMO, THFE	.	3	.	15	8	2	1	29
/RIMO, RIMO	3	6	.	10	.	3	.	22
ABLA/OSCH	.	.	.	12	.	.	.	12
ABLA/JUCO	.	.	.	.	.	.	12	12
								573
***Pinus contorta* series[1]**								
PICO/CACA c.t.	.	.	.	.	.	5	4	9
PICO/VACA c.t.	.	.	.	.	.	16	13	29
PICO/VASC c.t.	.	.	.	.	.	11	7	18
PICO/JUCO c.t.	.	.	.	.	.	.	14	14
PICO/ARUV h.t.	.	.	.	.	.	11	13	24
PICO/BERE c.t.	.	.	.	.	.	8	12	20
PICO/CARO h.t.	.	.	.	.	.	8	.	8
								122
Unclassified stands								
Populus tremuloides[2]	.	3	.	34	1	4	16	58
Other (ecotonal or unusual communities)	.	5	1	20	4	8	4	42
Total number of plots	14	150	9	393	45	181	324	1,116

[1]c.t. = community type; h.t. = habitat type.
[2]Cover type with several *P. tremuloides* community types represented.

APPENDIX B. DISTRIBUTION OF MAJOR TREE SPECIES IN NORTHERN UTAH HABITAT TYPES SHOWING THEIR DYNAMIC STATUS AS INTERPRETED FROM SAMPLE STAND DATA

C = major climax species
S = major seral species
() = in certain areas of type

c = minor climax species
s = minor seral species
a = accidental

HABITAT TYPE, PHASE	MAJOR TREE SPECIES											
	JUSC	PIFL	PIPO	PSME	PIPU	ABCO	PICO	PIEN	ABLA	POTR	ACGR	QUGA
PIFL/CELE	.	C	.	c	.	.	.	.	.	.	.	.
PIFL/BERE	(s)	C	.	c	.	.	.	.	.	.	.	.
PIPO/CAGE	.	.	C	a	.	.	(s)	.	.	(s)	.	.
PIPO/FEID, ARPA	.	.	C	a	.	.	(s)	.	.	(S)	.	.
/FEID, ARTR	s	.	C	a	.	.	(S)	.	.	(S)	.	.
/FEID, FEID	(s)	.	C	a	.	.	(s)	.	.	(s)	.	.
PSME/PHMA	(s)	.	.	C	.	a	(s)	.	a	(s)	(s)	.
PSME/ACGL	(s)	(s)	.	C	.	a	(s)	.	a	(s)	(s)	.
PSME/CELE	(s)	(s)	.	C	.	.	.	.	.	.	(s)	.
PSME/OSCH	(s)	.	.	C	.	.	(S)	.	a	(S)	(S)	.
PSME/BERE, CAGE	.	.	(S)	C	.	a	(s)	.	a	(s)	(s)	(s)
/BERE, JUCO	.	(s)	(S)	C	.	.	(S)	.	a	(S)	.	.
/BERE, SYOR	.	(s)	.	C	.	.	.	.	a	.	.	.
/BERE, BERE	(s)	(s)	(S)	C	a	a	(S)	.	.	(s)	(S)	.
PSME/SYOR	(s)	(s)	(s)	C	.	.	(S)	.	.	(s)	.	.
PIPU/AGSP	s	(s)	(s)	(S)	C	.	(s)	.	a	s	.	.
PIPU/BERE	.	.	.	S	C	.	(S)	.	a	S	.	.
ABCO/PHMA	(s)	.	.	S	.	C	.	.	a	(s)	(S)	(s)
ABCO/OSCH	.	.	.	S	.	C	.	(s)	a	(S)	(S)	.
ABCO/BERE, SYOR	(s)	(s)	.	(S)	.	C	.	.	.	.	(S)	(S)
/BERE, BERE	(s)	.	.	S	.	C	(s)	.	a	(s)	(S)	.
PIEN/EQAR	.	.	.	.	(c)	.	(S)	C	c	.	.	.
PIEN/CALE	.	.	.	.	.	.	(S)	C	(c)	.	.	.
PIEN/VACA	.	.	.	.	.	.	(S)	C	a	(S)	.	.
PIEN/VASC	.	.	.	a	.	.	(S)	C	a	.	.	.
ABLA/CACA	.	.	.	.	(s)	.	S	c	C	(S)	.	.
ABLA/STAM	.	.	.	.	.	.	s	c	C	.	.	.
ABLA/ACRU	.	.	.	(S)	(s)	(s)	.	(S)	C	(S)	(s)	.
ABLA/PHMA	.	.	.	S	.	(S)	.	(S)	C	(s)	(s)	.
ABLA/ACGL	.	(s)	.	S	.	(s)	(S)	(S)	C	(S)	(s)	.
ABLA/VACA	.	.	.	(s)	.	.	S	S	C	(s)	.	.
ABLA/VAGL	.	(s)	.	(s)	.	.	(S)	S	C	(S)	.	.
ABLA/VASC, ARLA	.	.	.	.	.	.	(S)	c	C	.	.	.
/VASC, CAGE	.	.	.	.	.	.	S	S	C	.	.	.
/VASC, VASC	.	.	.	(s)	.	.	S	S	C	(s)	.	.
ABLA/CARU	.	.	.	(S)	.	.	S	.	C	(s)	.	.
ABLA/PERA, PSME	.	.	.	S	.	.	(S)	S	C	(S)	.	.
/PERA, PERA	.	.	.	.	.	.	(S)	(c)	C	(S)	.	.
ABLA/BERE, PIFL	.	c	.	S	.	.	(s)	(S)	C	(s)	(s)	.
/BERE, RIMO	.	(s)	.	(S)	(s)	.	(S)	S	C	(S)	.	.
/BERE, CAGE	.	.	.	(S)	(S)	.	(S)	(S)	C	S	.	.
/BERE, JUCO	.	.	.	(S)	(S)	.	S	(s)	C	S	.	.
/BERE, PSME	.	.	.	S	(S)	(S)	(S)	(S)	C	(S)	(s)	.
/BERE, BERE	.	.	.	.	.	(s)	S	(S)	C	S	.	.
ABLA/RIMO, TRSP	.	.	.	.	.	.	(s)	c	C	.	.	.
/RIMO, PICO	.	.	.	.	.	.	S	S	C	(S)	.	.
/RIMO, THFE	.	.	.	(s)	.	.	(S)	S	C	(S)	.	.
/RIMO, RIMO	.	.	.	(S)	.	.	.	S	C	(s)	.	.
ABLA/OSCH	.	.	.	.	.	.	.	(s)	C	S	.	.
ABLA/JUCO	.	.	.	(S)	.	.	S	S	C	(s)	.	.

APPENDIX C-1. CONSTANCY AND AVERAGE CANOPY COVER (THE LATTER IN PARENTHESES) OF IMPORTANT PLANTS IN NORTHERN UTAH CONIFEROUS FOREST HABITAT TYPES AND PHASES (SEE BELOW FOR CODES)

	PINUS FLEXILIS SERIES	PINUS PONDEROSA SERIES					PSEUDOTSUGA MENZIESII SERIES			
	CELE h.t.	BERE h.t.	CAGE h.t.	FEID h.t. ARPA phase	FEID h.t. ARTR phase	FEID h.t. FEID phase	PHMA h.t.	ACGL h.t.	CELE h.t.	OSCH h.t.
Number of Stands	7	5	8	8	5	15	44	17	10	27
TREES										
Abies concolor	(0)	(0)	(0)	(0)	(0)	(0)	1(1)	1(4)	(0)	(0)
Abies lasiocarpa	(0)	2(+)	(0)	1(+)	(0)	(0)	+(1)	2(1)	(0)	1(+)
Picea engelmannii	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	+(+)
Picea pungens	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Pinus contorta	(0)	(0)	4(8)	5(4)	2(17)	3(5)	+(12)	2(1)	(0)	+(25)
Pinus flexilis	10(16)	10(25)	(0)	(0)	(0)	(0)	(0)	1(8)	2(3)	(0)
Pinus ponderosa	(0)	(0)	10(48)	10(37)	10(34)	10(37)	(0)	(0)	(0)	(0)
Pseudotsuga menziesii	9(8)	8(7)	1(2)	5(+)	2(2)	1(+)	10(71)	10(74)	10(27)	10(67)
Juniperus scopulorum	1(+)	6(5)	(0)	(0)	7(1)	3(1)	3(3)	2(1)	5(2)	2(2)
Populus tremuloides	(0)	(0)	5(7)	6(16)	2(38)	3(4)	2(5)	3(8)	(0)	4(17)
Acer grandidentatum	(0)	(0)	(0)	(0)	(0)	(0)	5(10)	2(11)	1(11)	4(17)
Quercus gambelii	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
SHRUBS AND SUBSHRUBS										
Acer glabrum	(0)	2(1)	(0)	(0)	(0)	(0)	4(15)	10(15)	(0)	1(3)
Amelanchier alnifolia	4(1)	10(1)	9(10)	10(2)	8(1)	5(1)	8(11)	9(8)	9(4)	9(9)
Arctostaphylos patula	(0)	(0)	(0)	10(14)	2(+)	2(1)	(0)	(0)	(0)	(0)
Arctostaphylos uva-ursi	(0)	(0)	5(9)	4(1)	3(4)	1(1)	(0)	1(+)	(0)	(0)
Artemisia tridentata	10(4)	8(5)	4(+)	5(1)	10(14)	7(1)	+(+)	(0)	8(1)	(0)
Berberis repens	10(4)	10(3)	9(3)	6(1)	7(1)	7(1)	8(3)	10(2)	9(6)	6(4)
Ceanothus velutinus	1(1)	6(1)	1(+)	(0)	(0)	(0)	+(+)	(0)	6(4)	(0)
Cercocarpus ledifolius	10(15)	4(+)	(0)	(0)	(0)	1(+)	1(1)	1(+)	10(37)	+(+)
Cercocarpus montanus	(0)	2(+)	(0)	4(3)	5(3)	4(1)	+(+)	(0)	(0)	(0)
Chrysothamnus viscidiflorus	7(1)	6(1)	(0)	(0)	2(1)	1(+)	+(+)	(0)	5(1)	(0)
Clematis columbiana	(0)	(0)	(0)	(0)	(0)	(0)	3(2)	2(2)	(0)	3(10)
Clematis pseudoalpina	(0)	2(+)	(0)	(0)	(0)	(0)	+(1)	2(3)	(0)	+(1)
Juniperus communis	(0)	(0)	6(2)	10(2)	5(2)	5(2)	+(1)	1(19)	(0)	(0)
Lonicera involucrata	(0)	(0)	(0)	(0)	(0)	(0)	(0)	2(1)	(0)	+(2)
Lonicera utahensis	(0)	(0)	(0)	(0)	(0)	(0)	+(1)	1(1)	(0)	1(1)
Pachistima myrsinites	7(4)	10(3)	8(1)	(0)	2(+)	1(+)	9(6)	9(8)	9(10)	6(3)
Physocarpus malvaceus	(0)	(0)	(0)	(0)	(0)	(0)	10(62)	2(2)	(0)	2(2)
Prunus virginiana	3(6)	10(8)	1(+)	(0)	(0)	(0)	7(12)	8(5)	7(7)	6(20)
Purshia tridentata	1(4)	2(+)	1(+)	9(1)	7(2)	5(1)	(0)	(0)	(0)	(0)
Ribes cereum	(0)	2(2)	(0)	1(+)	3(+)	1(1)	+(2)	2(1)	(0)	+(1)
Ribes montigenum	(0)	(0)	(0)	(0)	(0)	(0)	+(+)	(0)	(0)	(0)
Ribes viscosissimum	(0)	(0)	(0)	(0)	(0)	(0)	1(2)	3(2)	(0)	3(1)
Rosa nutkana	1(+)	2(+)	6(1)	1(1)	3(1)	1(+)	+(2)	1(+)	(0)	+(2)
Rosa woodsii	(0)	2(+)	1(1)	1(+)	3(2)	1(+)	6(2)	6(2)	5(2)	5(3)
Rubus parviflorus	(0)	(0)	(0)	(0)	(0)	(0)	1(5)	2(2)	(0)	1(2)
Sambucus cerulea	(0)	(0)	(0)	(0)	(0)	1(+)	+(+)	1(+)	(0)	1(1)
Sambucus racemosa	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Shepherdia canadensis	1(1)	(0)	(0)	3(1)	(0)	(0)	1(1)	2(1)	(0)	(0)
Sorbus scopulina	(0)	(0)	(0)	(0)	(0)	(0)	1(2)	3(8)	(0)	1(1)
Symphoricarpos oreophilus	10(3)	10(2)	8(9)	9(1)	8(1)	4(2)	8(5)	9(6)	10(18)	7(6)
Vaccinium caespitosum	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Vaccinium globulare	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Vaccinium scoparium	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
GRAMINOIDS										
Agropyron spicatum	6(2)	6(1)	(0)	4(1)	5(1)	3(3)	(0)	(0)	5(9)	+(+)
Agropyron trachycaulum	6(2)	6(7)	1(1)	(0)	2(+)	(0)	1(+)	1(+)	6(2)	1(5)
Bromus anomalus	(0)	4(+)	(0)	(0)	(0)	(0)	+(+)	1(+)	1(+)	(0)
Bromus carinatus	(0)	2(+)	(0)	(0)	(0)	(0)	2(10)	2(1)	5(2)	4(9)
Bromus ciliatus	(0)	(0)	1(1)	4(+)	(0)	(0)	+(1)	1(1)	(0)	(0)
Calamagrostis canadensis	(0)	(0)	(0)	(0)	(0)	(0)	+(+)	(0)	(0)	(0)
Calamagrostis rubescens	(0)	(0)	(0)	(0)	(0)	(0)	+(6)	2(28)	(0)	4(1)
Carex geyeri	(0)	(0)	10(54)	(0)	(0)	1(3)	4(8)	3(6)	(0)	3(21)
Carex rossii	1(+)	2(1)	4(1)	10(1)	5(1)	7(2)	+(+)	2(1)	1(+)	1(1)
Deschampsia cespitosa	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Elymus glaucus	(0)	(0)	1(+)	(0)	(0)	(0)	3(2)	4(6)	1(+)	6(16)
Festuca idahoensis	1(+)	(0)	5(1)	10(4)	8(19)	9(4)	+(+)	(0)	2(+)	(0)
Festuca ovina	(0)	(0)	3(+)	(0)	2(1)	1(9)	(0)	1(1)	(0)	(0)
Leucopoa kingii	7(4)	10(3)	1(1)	(0)	3(3)	1(4)	+(5)	2(1)	8(3)	+(+)
Luzula spicata	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Poa fendleriana	1(6)	(0)	1(+)	9(3)	3(4)	5(4)	+(2)	1(+)	(0)	(0)
Poa nervosa	4(1)	2(1)	8(1)	(0)	3(6)	4(2)	4(2)	4(1)	4(4)	3(15)
Sitanion hystrix	3(1)	(0)	4(+)	5(+)	8(2)	5(1)	(0)	(0)	(0)	(0)
Trisetum spicatum	(0)	(0)	(0)	1(1)	(0)	(0)	(0)	(0)	(0)	+(+)

(+) = COVER 0.5%; CODE TO CONSTANCY VALUES: + = 0-5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%, 4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

	PINUS FLEXILIS SERIES		PINUS PONDEROSA SERIES				PSEUDOTSUGA MENZIESII SERIES			
	CELE h.t.	BERE h.t.	CAGE h.t.	FEID h.t. ARPA phase	FEID h.t. ARTR phase	FEID h.t. FEID phase	PHMA h.t.	ACGL h.t.	CELE h.t.	OSCH h.t.
Number of Stands	7	5	8	8	6	15	44	17	10	27
FORBS AND FERN ALLIES										
Achillea millefolium	4(1)	6(+)	8(1)	1(+)	7(1)	3(+)	2(+)	2(1)	7(+)	4(1)
Aconitum columbianum	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Actaea rubra	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(2)	(0)	1(6)
Antennaria microphylla	(0)	(0)	9(+)	8(1)	10(+)	7(+)	(0)	(0)	(0)	(0)
Antennaria parvifolia	(0)	(0)	1(+)	3(1)	(0)	1(1)	(0)	1(+)	(0)	(0)
Aquilegia coerulea	(0)	(0)	(0)	(0)	2(+)	(0)	(0)	1(3)	(0)	1(1)
Arnica cordifolia	(0)	(0)	1(+)	(0)	2(1)	(0)	8(17)	5(8)	4(3)	6(13)
Arnica latifolia	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Aster engelmannii	1(1)	2(1)	(0)	(0)	(0)	(0)	4(2)	5(1)	3(2)	2(1)
Aster glaucodes	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	2(+)	(0)
Aster perelegans	1(+)	6(1)	(0)	(0)	(0)	(0)	+(2)	1(1)	3(1)	1(1)
Astragalus miser	(0)	(0)	(0)	(0)	3(1)	(0)	(0)	(0)	(0)	(0)
Balsamorhiza sagittata	9(2)	2(3)	3(+)	(0)	(0)	(0)	(0)	(0)	6(5)	(0)
Caltha leptosepala	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Castilleja linariaefolia	3(+)	6(+)	3(+)	4(+)	(0)	(0)	+(+)	1(+)	(0)	(0)
Castilleja minitata	(0)	(0)	1(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Delphinium occidentale	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(+)
Disporum trachycarpum	(0)	(0)	(0)	(0)	(0)	(0)	6(2)	6(1)	1(+)	4(1)
Epilobium angustifolium	(0)	(0)	(0)	1(+)	(0)	(0)	1(+)	2(+)	(0)	1(+)
Equisetum arvense	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Erigeron peregrinus	(0)	(0)	1(+)	4(1)	(0)	(0)	(0)	(0)	(0)	(0)
Erigeron speciosus	1(+)	2(+)	(0)	(0)	2(+)	2(+)	+(+)	2(+)	4(1)	+(+)
Fragaria vesca	(0)	(0)	(0)	(0)	(0)	(0)	5(3)	7(2)	1(1)	4(4)
Fragaria virginiana	(0)	(0)	3(+)	(0)	(0)	(0)	+(1)	1(+)	(0)	1(1)
Frasera speciosa	(0)	(0)	(0)	3(+)	(0)	(0)	1(+)	3(1)	1(+)	+(+)
Galium boreale	(0)	(0)	6(+)	(0)	2(+)	1(+)	(0)	1(+)	(0)	3(2)
Geranium richardsonii	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(+)	(0)	(0)
Geranium viscosissimum	1(+)	4(1)	(0)	(0)	(0)	(0)	1(+)	2(+)	2(1)	4(1)
Haplopappus parryi	(0)	(0)	(0)	(0)	(0)	1(+)	(0)	1(+)	(0)	(0)
Hieracium albiflorum	(0)	(0)	1(+)	(0)	(0)	1(+)	+(1)	3(+)	(0)	1(1)
Hieracium gracile	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Lathyrus lanszwertii	(0)	(0)	(0)	(0)	(0)	(0)	1(1)	(0)	(0)	2(20)
Lathyrus pauciflorus	(0)	(0)	(0)	(0)	(0)	(0)	2(1)	(0)	(0)	+(4)
Ligusticum filicinum	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	+(+)
Lomatium nuttallii	4(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	4(1)	(0)
Lupinus argenteus	(0)	(0)	1(+)	(0)	2(+)	(0)	(0)	(0)	(0)	(0)
Mertensia ciliata	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Mitella pentandra	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Mitella stauropetala	(0)	(0)	(0)	(0)	(0)	(0)	7(2)	6(2)	(0)	6(4)
Osmorhiza chilensis	(0)	2(+)	(0)	(0)	(0)	(0)	5(2)	6(5)	2(1)	9(10)
Osmorhiza depauperata	(0)	(0)	1(+)	(0)	(0)	(0)	+(2)	1(1)	(0)	2(12)
Pedicularis racemosa	1(+)	(0)	(0)	(0)	(0)	(0)	+(+)	1(3)	(0)	(0)
Penstemon whippleanus	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Polemonium foliosissimum	(0)	(0)	(0)	(0)	(0)	(0)	+(+)	(0)	1(+)	1(1)
Polemonium pulcherrimum	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Polygonum bistortoides	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Potentilla glandulosa	(0)	(0)	1(+)	(0)	(0)	(0)	(0)	1(4)	(0)	+(+)
Potentilla gracilis	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(2)	(0)	(0)
Pyrola asarifolia	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Pyrola secunda	(0)	(0)	(0)	(0)	(0)	(0)	+(3)	2(1)	(0)	1(+)
Saxifraga odontoloma	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Sedum lanceolatum	(0)	(0)	(0)	8(+)	3(+)	1(+)	+(1)	(0)	(0)	(0)
Senecio serra	(0)	(0)	(0)	(0)	(0)	(0)	+(+)	2(+)	(0)	3(1)
Senecio streptanthifolius	3(+)	(0)	(0)	(0)	2(+)	(0)	+(+)	1(+)	2(+)	+(+)
Senecio triangularis	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Sibbaldia procumbens	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Silene menziesii	(0)	2(+)	(0)	(0)	(0)	(0)	4(2)	5(1)	1(1)	5(1)
Smilacina racemosa	(0)	2(+)	(0)	(0)	(0)	(0)	8(4)	8(3)	3(1)	6(3)
Smilacina stellata	(0)	2(1)	(0)	1(1)	(0)	(0)	+(2)	2(1)	(0)	1(10)
Solidago spathulata	(0)	(0)	(0)	3(+)	2(+)	1(+)	(0)	1(+)	(0)	(0)
Stellaria jamesiana	(0)	(0)	4(2)	(0)	3(1)	1(+)	5(1)	2(+)	6(4)	6(2)
Streptopus amplexifolius	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Thalictrum fendleri	3(2)	4(2)	1(+)	(0)	2(+)	(0)	2(2)	6(5)	3(1)	7(2)
Viola adunca	(0)	(0)	(0)	(0)	(0)	(0)	4(4)	6(1)	1(+)	4(1)
Viola nuttallii	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(1)
Viola purpurea	(0)	4(+)	(0)	(0)	(0)	(0)	+(+)	(0)	4(+)	(0)

(+) = COVER <0.5%; CODE TO CONSTANCY VALUES: + = 0-5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%, 4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

	PSEUDOTSUGA MENZIESII SERIES (cont.)					PICEA PUNGENS SERIES		ABIES CONCOLOR SERIES	
	BERE h.t.				SYOR h.t.	AGSP h.t.	BERE h.t.	PHMA h.t.	OSCH h.t.
	CAGE phase	JUCO phase	SYOR phase	BERE phase					
Number of Stands	13	11	11	39	7	7	9	8	5
TREES									
Abies concolor	1(1)	(0)	(0)	+(4)	(0)	(0)	(0)	10(50)	10(51)
Abies lasiocarpa	2(1)	2(1)	2(2)	(0)	(0)	1(+)	3(1)	1(1)	2(+)
Picea engelmannii	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	2(1)
Picea pungens	(0)	(0)	(0)	+(+)	(0)	10(15)	10(34)	(0)	(0)
Pinus contorta	1(5)	4(22)	(0)	1(29)	1(16)	3(1)	4(46)	(0)	(0)
Pinus flexilis	(0)	2(6)	4(9)	1(4)	3(2)	6(4)	1(+)	(0)	(0)
Pinus ponderosa	2(26)	2(12)	(0)	1(17)	3(4)	6(9)	1(1)	(0)	(0)
Pseudotsuga menziesii	10(65)	10(48)	10(45)	10(69)	10(54)	10(28)	6(28)	10(33)	8(17)
Juniperus scopulorum	1(+)	2(+)	(0)	4(3)	3(2)	7(3)	1(+)	1(3)	(0)
Populus tremuloides	2(6)	5(26)	(0)	3(7)	4(5)	7(6)	9(18)	3(5)	2(47)
Acer grandidentatum	2(4)	(0)	(0)	3(22)	(0)	(0)	(0)	4(27)	4(10)
Quercus gambelii	2(11)	(0)	(0)	+(+)	(0)	(0)	(0)	3(12)	(0)
SHRUBS AND SUBSHRUBS									
Acer glabrum	2(2)	2(3)	(0)	3(1)	(0)	1(+)	4(2)	1(3)	4(13)
Amelanchier alnifolia	7(3)	7(1)	5(2)	7(4)	3(1)	4(1)	3(+)	9(14)	8(13)
Arctostaphylos patula	(0)	3(4)	(0)	(0)	1(1)	(0)	(0)	(0)	(0)
Arctostaphylos uva-ursi	2(5)	2(3)	(0)	1(1)	(0)	(0)	1(10)	(0)	(0)
Artemisia tridentata	1(8)	3(1)	8(2)	1(1)	7(1)	6(+)	(0)	(0)	(0)
Berberis repens	10(5)	9(7)	5(4)	10(3)	(0)	10(3)	8(2)	10(2)	8(1)
Ceanothus velutinus	(0)	(0)	(0)	+(+)	(0)	(0)	(0)	(0)	(0)
Cercocarpus ledifolius	1(5)	(0)	2(3)	2(3)	(0)	(0)	(0)	1(+)	(0)
Cercocarpus montanus	(0)	(0)	(0)	(0)	1(1)	1(1)	(0)	(0)	(0)
Chrysothamnus viscidiflorus	2(3)	(0)	2(1)	1(1)	3(2)	1(+)	(0)	(0)	(0)
Clematis columbiana	2(3)	(0)	(0)	1(1)	(0)	(0)	(0)	3(2)	2(1)
Clematis pseudoalpina	(0)	1(3)	(0)	1(2)	(0)	(0)	(0)	(0)	(0)
Juniperus communis	4(2)	10(16)	(0)	2(2)	9(10)	10(15)	10(13)	(0)	(0)
Lonicera involucrata	(0)	(0)	(0)	+(+)	(0)	(0)	(0)	1(1)	2(2)
Lonicera utahensis	1(+)	(0)	1(2)	(0)	(0)	(0)	(0)	(0)	2(1)
Pachistima myrsinites	5(6)	5(1)	8(2)	8(6)	(0)	7(2)	7(4)	9(17)	8(13)
Physocarpus malvaceus	2(4)	(0)	(0)	+(2)	(0)	(0)	(0)	10(39)	6(7)
Prunus virginiana	2(7)	(0)	4(+)	4(17)	1(2)	(0)	(0)	6(5)	6(5)
Purshia tridentata	1(+)	(0)	1(2)	+(15)	(0)	(0)	(0)	(0)	(0)
Ribes cereum	2(4)	2(1)	(0)	2(1)	4(2)	1(+)	(0)	(0)	(0)
Ribes montigenum	1(1)	2(1)	5(15)	(0)	1(2)	(0)	(0)	(0)	(0)
Ribes viscosissimum	3(+)	(0)	1(+)	+(1)	1(+)	(0)	1(+)	(0)	4(1)
Rosa nutkana	3(1)	(0)	3(1)	1(1)	3(+)	(0)	7(1)	1(+)	(0)
Rosa woodsii	3(1)	3(+)	(0)	5(1)	1(2)	1(+)	2(2)	4(2)	(0)
Rubus parviflorus	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	4(1)
Sambucus cerulea	2(+)	(0)	(0)	+(1)	(0)	(0)	(0)	1(+)	(0)
Sambucus racemosa	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(+)	(0)
Shepherdia canadensis	(0)	3(1)	(0)	+(+)	(0)	3(+)	6(+)	(0)	(0)
Sorbus scopulina	1(2)	(0)	(0)	1(3)	(0)	(0)	(0)	3(2)	2(5)
Symphoricarpos oreophilus	9(12)	9(8)	10(11)	9(3)	10(12)	10(2)	7(5)	10(4)	4(13)
Vaccinium caespitosum	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Vaccinium globulare	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Vaccinium scoparium	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
GRAMINOIDS									
Agropyron spicatum	3(14)	2(1)	1(4)	1(2)	3(5)	10(4)	(0)	(0)	(0)
Agropyron trachycaulum	4(2)	3(2)	5(2)	3(+)	4(2)	1(1)	6(1)	(0)	2(1)
Bromus anomalus	(0)	(0)	1(+)	(0)	(0)	(0)	(0)	(0)	(0)
Bromus carinatus	2(1)	(0)	4(2)	2(1)	(0)	(0)	(0)	1(+)	2(1)
Bromus ciliatus	1(+)	5(1)	(0)	+(+)	1(+)	(0)	2(1)	1(+)	(0)
Calamagrostis canadensis	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Calamagrostis rubescens	(0)	(0)	(0)	1(1)	(0)	(0)	(0)	(0)	(0)
Carex geyeri	10(23)	1(4)	(0)	2(1)	1(25)	(0)	7(21)	6(14)	2(1)
Carex rossii	2(4)	8(1)	1(+)	3(1)	7(1)	7(1)	6(1)	4(3)	2(+)
Deschampsia cespitosa	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Elymus glaucus	2(2)	(0)	2(+)	3(1)	(0)	(0)	(0)	3(1)	6(2)
Festuca idahoensis	(0)	2(1)	(0)	1(1)	4(1)	1(+)	(0)	(0)	(0)
Festuca ovina	1(1)	2(+)	(0)	+(2)	1(1)	(0)	(0)	(0)	(0)
Leucopoa kingii	2(10)	2(+)	9(3)	3(1)	6(1)	(0)	(0)	(0)	(0)
Luzula spicata	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Poa fendleriana	1(+)	5(1)	1(4)	2(1)	3(1)	3(+)	2(1)	(0)	(0)
Poa nervosa	5(6)	3(1)	6(6)	5(2)	4(1)	1(+)	2(1)	(0)	(0)
Sitanion hystrix	1(+)	2(1)	1(+)	1(+)	3(+)	(0)	1(+)	(0)	(0)
Trisetum spicatum	(0)	1(+)	(0)	(0)	(0)	3(+)	3(1)	(0)	2(+)

(+) = COVER <0.5%; CODE TO CONSTANCY VALUES: + = 0-5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%, 4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

	PSEUDOTSUGA MENZIESII SERIES (cont.) BERE h.t. CAGE phase	JUCO phase	SYOR phase	BERE phase	SYOR h.t.	PICEA PUNGENS SERIES AGSP h.t.	BERE h.t.	ABIES CONCOLOR SERIES PHMA h.t.	OSCH h.t.
Number of Stands	13	11	11	39	7	7	9	8	5
FORBS AND FERN ALLIES									
Achillea millefolium	2(+)	4(1)	4(+)	2(+)	3(+)	3(+)	4(1)	3(+)	(0)
Aconitum columbianum	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Actaea rubra	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	2(+)
Antennaria microphylla	2(+)	3(1)	(0)	1(+)	6(+)	(0)	1(+)	(0)	(0)
Antennaria parvifolia	(0)	2(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Aquilegia coerulea	1(+)	2(+)	2(3)	1(+)	1(+)	(0)	6(1)	(0)	2(1)
Arnica cordifolia	2(2)	2(2)	(0)	6(7)	(0)	(0)	4(+)	1(+)	(0)
Arnica latifolia	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Aster engelmannii	2(3)	(0)	4(2)	3(1)	(0)	(0)	(0)	6(1)	2(1)
Aster glaucodes	(0)	2(+)	1(2)	2(+)	(0)	(0)	1(+)	(0)	(0)
Aster perelegans	4(2)	(0)	3(1)	2(+)	(0)	(0)	(0)	(0)	(0)
Astragalus miser	1(10)	4(15)	(0)	1(2)	3(1)	(0)	4(9)	(0)	(0)
Balsamorhiza sagittata	1(3)	(0)	5(1)	1(+)	(0)	(0)	(0)	(0)	(0)
Caltha leptosepala	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Castilleja linariaefolia	1(+)	2(+)	1(+)	+(+)	3(+)	(0)	3(1)	1(+)	(0)
Castilleja miniata	(0)	(0)	1(+)	(0)	(0)	(0)	(0)	(0)	(0)
Delphinium occidentale	1(1)	(0)	1(+)	(0)	(0)	(0)	(0)	(0)	2(+)
Disporum trachycarpum	2(1)	(0)	(0)	3(1)	(0)	(0)	(0)	4(1)	2(+)
Epilobium angustifolium	2(+)	(0)	(0)	1(+)	(0)	(0)	(0)	1(1)	2(+)
Equisetum arvense	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Erigeron peregrinus	1(+)	(0)	1(1)	(0)	(0)	(0)	3(1)	(0)	(0)
Erigeron speciosus	1(+)	4(2)	3(3)	2(1)	(0)	(0)	(0)	1(+)	(0)
Fragaria vesca	3(1)	(0)	1(+)	4(1)	(0)	(0)	(0)	3(+)	2(+)
Fragaria virginiana	2(2)	4(1)	(0)	1(1)	3(1)	1(+)	4(1)	(0)	(0)
Frasera speciosa	2(1)	3(1)	1(+)	2(+)	(0)	4(1)	6(1)	(0)	(0)
Galium boreale	2(1)	5(1)	(0)	2(+)	1(+)	4(+)	8(1)	(0)	(0)
Geranium richardsonii	(0)	(0)	(0)	(0)	(0)	(0)	2(1)	(0)	(0)
Geranium viscosissimum	(0)	(0)	2(1)	2(+)	1(1)	(0)	1(2)	1(2)	(0)
Haplopappus parryi	(0)	1(7)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Hieracium albiflorum	(0)	(0)	(0)	+(+)	1(+)	(0)	1(+)	(0)	2(+)
Hieracium gracile	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Lathyrus lanszwertii	1(2)	(0)	2(2)	+(2)	(0)	(0)	(0)	4(1)	2(1)
Lathyrus pauciflorus	1(+)	(0)	1(3)	(0)	(0)	(0)	(0)	1(+)	(0)
Ligusticum filicinum	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Lomatium nuttallii	(0)	(0)	4(2)	(0)	(0)	(0)	(0)	(0)	(0)
Lupinus argenteus	1(+)	2(1)	(0)	(0)	(0)	(0)	4(2)	(0)	(0)
Mertensia ciliata	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Mitella pentandra	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Mitella stauropetala	2(2)	(0)	2(1)	2(1)	(0)	(0)	(0)	8(1)	2(2)
Osmorhiza chilensis	1(1)	(0)	1(7)	5(1)	(0)	(0)	1(+)	8(1)	8(11)
Osmorhiza depauperata	(0)	(0)	(0)	1(1)	1(+)	(0)	2(+)	(0)	(0)
Pedicularis racemosa	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Penstemon whippleanus	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Polemonium foliosissimum	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Polemonium pulcherrimum	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Polygonum bistortoides	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Potentilla glandulosa	1(+)	(0)	2(1)	(0)	(0)	(0)	1(+)	3(+)	(0)
Potentilla gracilis	(0)	(0)	(0)	+(+)	(0)	(0)	2(+)	(0)	(0)
Pyrola asarifolia	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Pyrola secunda	(0)	2(+)	(0)	+(1)	(0)	(0)	4(1)	1(+)	2(1)
Saxifraga odontoloma	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Sedum lanceolatum	(0)	2(+)	(0)	1(+)	1(+)	(0)	(0)	(0)	(0)
Senecio serra	(0)	(0)	1(1)	+(+)	(0)	(0)	(0)	(0)	(0)
Senecio streptanthifolius	(0)	2(1)	7(+)	1(+)	(0)	1(+)	2(1)	3(2)	2(1)
Senecio triangularis	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Sibbaldia procumbens	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Silene menziesii	1(+)	(0)	1(+)	4(1)	(0)	(0)	(0)	5(+)	2(+)
Smilacina racemosa	4(1)	(0)	2(+)	5(3)	(0)	(0)	(0)	6(1)	4(1)
Smilacina stellata	(0)	3(+)	(0)	1(1)	(0)	3(+)	3(1)	(0)	(0)
Solidago spathulata	(0)	4(1)	(0)	(0)	3(1)	(0)	1(2)	(0)	(0)
Stellaria jamesiana	5(3)	1(4)	8(2)	4(4)	1(+)	(0)	3(1)	1(+)	2(5)
Streptopus amplexifolius	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Thalictrum fendleri	6(1)	4(2)	3(1)	3(2)	4(1)	4(+)	8(1)	1(20)	2(1)
Viola adunca	2(1)	(0)	1(+)	4(2)	(0)	(0)	2(1)	(0)	4(1)
Viola nuttallii	1(+)	(0)	(0)	1(1)	(0)	(0)	(0)	1(+)	(0)
Viola purpurea	(0)	(0)	1(+)	1(1)	(0)	(0)	(0)	(0)	(0)

(+) = COVER <0.5%; CODE TO CONSTANCY VALUES: + = 0-5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%, 4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

	ABIES CONCOLOR SERIES (cont.)		PICEA ENGELMANNII SERIES				ABIES LASIOCARPA SERIES		
	BERE h.t.		EQAR h.t.	CALE h.t.	VACA h.t.	VASC h.t.	CACA h.t.	STAM h.t.	ACRU h.t.
	SYOR phase	BERE phase							
Number of Stands	8	13	6	5	14	17	5	3	11
TREES									
Abies concolor	10(42)	10(35)	(0)	(0)	(0)	(0)	(0)	(0)	1(9)
Abies lasiocarpa	(0)	2(1)	8(29)	6(6)	1(2)	2(1)	10(7)	10(29)	10(53)
Picea engelmannii	(0)	(0)	10(33)	10(43)	10(34)	10(32)	8(21)	10(63)	4(31)
Picea pungens	(0)	(0)	(0)	(0)	(0)	(0)	2(3)	(0)	1(4)
Pinus contorta	(0)	1(9)	5(14)	6(48)	6(53)	6(50)	10(29)	10(4)	(0)
Pinus flexilis	1(7)	1(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Pinus ponderosa	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Pseudotsuga menziesii	4(10)	9(45)	(0)	(0)	(0)	1(2)	(0)	(0)	6(40)
Juniperus scopulorum	4(1)	2(4)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Populus tremuloides	(0)	5(6)	2(+)	(0)	1(40)	(0)	4(41)	(0)	5(23)
Acer grandidentatum	4(28)	2(21)	(0)	(0)	(0)	(0)	(0)	(0)	5(5)
Quercus gambelii	5(12)	2(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
SHRUBS AND SUBSHRUBS									
Acer glabrum	(0)	3(5)	(0)	(0)	(0)	(0)	(0)	(0)	5(5)
Amelanchier alnifolia	4(8)	6(3)	(0)	(0)	(0)	(0)	2(3)	(0)	5(4)
Arctostaphylos patula	(0)	1(4)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Arctostaphylos uva-ursi	(0)	(0)	(0)	(0)	(0)	(0)	2(1)	(0)	(0)
Artemisia tridentata	1(+)	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Berberis repens	9(15)	10(3)	(0)	(0)	(0)	(0)	2(2)	(0)	5(1)
Ceanothus velutinus	1(25)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Cercocarpus ledifolius	5(9)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Cercocarpus montanus	(0)	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Chrysothamnus viscidiflorus	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clematis columbiana	(0)	(0)	(0)	(0)	(0)	(0)	2(1)	(0)	5(3)
Clematis pseudoalpina	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Juniperus communis	(0)	2(4)	3(+)	(0)	5(2)	5(5)	4(1)	(0)	(0)
Lonicera involucrata	(0)	(0)	8(2)	(0)	(0)	(0)	6(1)	3(2)	1(1)
Lonicera utahensis	(0)	2(1)	2(+)	(0)	(0)	(0)	(0)	3(+)	5(5)
Pachistima myrsinites	9(4)	7(7)	2(1)	(0)	1(1)	(0)	4(2)	3(+)	6(3)
Physocarpus malvaceus	1(8)	4(3)	(0)	(0)	(0)	(0)	(0)	(0)	4(13)
Prunus virginiana	6(12)	2(2)	(0)	(0)	(0)	(0)	(0)	(0)	5(4)
Purshia tridentata	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Ribes cereum	3(2)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(+)
Ribes montigenum	(0)	(0)	2(15)	4(+)	6(1)	5(1)	4(2)	3(2)	3(13)
Ribes viscosissimum	(0)	2(1)	(0)	(0)	(0)	1(+)	(0)	(0)	2(3)
Rosa nutkana	3(1)	2(2)	(0)	(0)	1(+)	(0)	4(2)	3(+)	4(2)
Rosa woodsii	4(1)	4(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Rubus parviflorus	(0)	(0)	(0)	(0)	(0)	(0)	2(1)	3(+)	4(1)
Sambucus cerulea	3(2)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Sambucus racemosa	(0)	1(+)	2(15)	(0)	(0)	(0)	(0)	(0)	2(1)
Shepherdia canadensis	(0)	1(2)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Sorbus scopulina	1(2)	(0)	(0)	(0)	(0)	(0)	(0)	3(+)	5(1)
Symphoricarpos oreophilus	9(20)	10(7)	(0)	(0)	(0)	(0)	2(+)	(0)	8(4)
Vaccinium caespitosum	(0)	(0)	3(3)	6(4)	10(8)	1(+)	6(1)	(0)	(0)
Vaccinium globulare	(0)	(0)	(0)	(0)	(0)	(0)	(0)	3(+)	(0)
Vaccinium scoparium	(0)	(0)	3(6)	8(34)	8(36)	10(39)	8(6)	10(13)	(0)
GRAMINOIDS									
Agropyron spicatum	(0)	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Agropyron trachycaulum	1(+)	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Bromus anomalus	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(2)
Bromus carinatus	5(1)	2(+)	(0)	(0)	(0)	(0)	(0)	(0)	3(2)
Bromus ciliatus	(0)	2(1)	7(1)	(0)	1(1)	1(1)	6(9)	3(3)	2(+)
Calamagrostis canadensis	(0)	(0)	8(16)	(0)	(0)	1(+)	10(41)	7(2)	(0)
Calamagrostis rubescens	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Carex geyeri	1(+)	5(11)	2(1)	(0)	2(2)	(0)	4(1)	3(1)	1(1)
Carex rossii	(0)	1(+)	(0)	4(1)	9(1)	8(2)	2(1)	10(1)	3(1)
Deschampsia cespitosa	(0)	(0)	2(2)	8(47)	2(22)	(0)	4(23)	(0)	(0)
Elymus glaucus	3(8)	1(2)	5(3)	(0)	(0)	(0)	6(4)	7(3)	3(3)
Festuca idahoensis	1(+)	(0)	(0)	(0)	1(+)	(0)	(0)	(0)	(0)
Festuca ovina	(0)	(0)	(0)	4(2)	4(2)	1(15)	(0)	(0)	(0)
Leucopoa kingii	3(+)	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Luzula spicata	(0)	(0)	(0)	8(+)	4(1)	1(+)	2(+)	(0)	(0)
Poa fendleriana	1(+)	(0)	(0)	(0)	1(+)	(0)	(0)	(0)	(0)
Poa nervosa	1(+)	1(1)	(0)	6(1)	6(1)	8(1)	6(1)	7(1)	(0)
Sitanion hystrix	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Trisetum spicatum	(0)	(0)	3(+)	10(1)	7(2)	6(+)	10(1)	7(+)	(0)

(+) = COVER <0.5%; CODE TO CONSTANCY VALUES: + = 0-5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%, 4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

APPENDIX C-1 (con.)

	ABIES CONCOLOR SERIES (cont.)		PICEA ENGELMANNII SERIES				ABIES LASIOCARPA SERIES		
	BERE h.t.		EQAR h.t.	CALE h.t.	VACA h.t.	VASC h.t.	CACA h.t.	STAM h.t.	ACRU h.t.
	SYOR phase	BERE phase							
Number of Stands	8	13	6	5	14	17	5	3	11
FORBS AND FERN ALLIES									
Achillea millefolium	3(+)	2(+)	3(2)	6(6)	7(1)	7(+)	6(1)	7(+)	(0)
Aconitum columbianum	(0)	(0)	7(7)	(0)	(0)	(0)	4(1)	3(+)	(0)
Actaea rubra	(0)	(0)	(0)	(0)	(0)	(0)	2(1)	3(1)	10(12)
Antennaria microphylla	(0)	(0)	(0)	10(6)	6(+)	2(3)	(0)	(0)	(0)
Antennaria parvifolia	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Aquilesia coerulea	(0)	1(+)	2(2)	(0)	1(+)	2(+)	2(1)	7(+)	5(3)
Arnica cordifolia	(0)	2(2)	3(1)	2(15)	4(2)	6(1)	10(1)	7(2)	6(5)
Arnica latifolia	(0)	(0)	2(3)	4(1)	1(1)	2(1)	(0)	7(12)	(0)
Aster enselmannii	4(1)	4(2)	3(19)	(0)	1(+)	(0)	(0)	3(+)	5(4)
Aster slaucodes	(0)	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Aster perelesans	3(+)	2(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Astrasalus miser	(0)	(0)	(0)	(0)	(0)	1(1)	(0)	(0)	(0)
Balsamorhiza sasittata	4(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Caltha leptosepala	(0)	(0)	2(50)	10(5)	(0)	(0)	4(23)	3(25)	(0)
Castilleja linariaefolia	(0)	1(+)	2(+)	(0)	1(+)	(0)	(0)	(0)	(0)
Castilleja minitata	(0)	(0)	(0)	(0)	(0)	(0)	(0)	3(+)	(0)
Delphinium occidentale	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(+)
Disporum trachycarpum	(0)	2(2)	(0)	(0)	(0)	(0)	2(+)	(0)	5(1)
Epilobium ansustifolium	(0)	(0)	7(1)	(0)	4(+)	2(+)	2(+)	10(+)	2(2)
Equisetum arvense	(0)	(0)	10(34)	(0)	(0)	(0)	4(1)	3(+)	(0)
Eriseron peresrinus	(0)	(0)	5(4)	8(6)	6(1)	6(1)	8(4)	10(2)	1(+)
Eriseron speciosus	5(2)	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Frasaria vesca	(0)	2(1)	(0)	(0)	(0)	(0)	2(1)	(0)	5(2)
Frasaria virsiniana	(0)	(0)	7(1)	2(1)	4(1)	2(+)	10(1)	3(2)	1(+)
Frasera speciosa	(0)	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	2(+)
Galium boreale	1(+)	2(+)	2(1)	(0)	3(1)	(0)	10(2)	3(3)	1(10)
Geranium richardsonii	(0)	(0)	8(8)	(0)	3(+)	1(+)	8(4)	3(+)	(0)
Geranium viscosissimum	1(+)	1(+)	2(10)	2(3)	1(+)	1(10)	(0)	(0)	2(+)
Haplopappus parrsi	(0)	(0)	(0)	(0)	1(1)	(0)	(0)	(0)	(0)
Hieracium albiflorum	(0)	(0)	2(+)	(0)	(0)	(0)	(0)	(0)	1(+)
Hieracium sracile	(0)	(0)	(0)	2(1)	1(1)	1(+)	(0)	3(+)	(0)
Lathyrus lanszwertii	3(+)	2(3)	3(5)	(0)	(0)	(0)	(0)	(0)	5(6)
Lathyrus pauciflorus	(0)	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	1(1)
Lisusticum filicinum	(0)	(0)	2(1)	(0)	(0)	(0)	2(+)	7(+)	(0)
Lomatium nuttallii	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Lupinus arsenteus	(0)	(0)	(0)	(0)	2(2)	2(1)	(0)	(0)	(0)
Mertensia ciliata	(0)	1(+)	2(+)	2(+)	(0)	(0)	4(+)	10(7)	(0)
Mitella pentandra	(0)	(0)	5(2)	(0)	(0)	(0)	(0)	7(2)	(0)
Mitella stauropetala	(0)	2(1)	2(5)	(0)	(0)	(0)	(0)	3(3)	8(5)
Osmorhiza chilensis	5(3)	5(1)	(0)	(0)	(0)	(0)	2(8)	3(2)	7(4)
Osmorhiza depauperata	(0)	(0)	5(5)	2(2)	1(1)	1(+)	8(2)	7(5)	3(11)
Pedicularis racemosa	(0)	(0)	2(+)	4(1)	1(1)	1(+)	(0)	3(1)	3(5)
Penstemon whippleanus	(0)	(0)	(0)	(0)	(0)	2(+)	(0)	(0)	(0)
Polemonium foliosissimum	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	4(+)
Polemonium pulcherrimum	(0)	(0)	(0)	(0)	1(+)	2(+)	2(2)	3(+)	(0)
Polysonum bistortoides	(0)	(0)	2(+)	10(2)	4(2)	1(1)	4(2)	(0)	(0)
Potentilla slandulosa	(0)	1(+)	(0)	(0)	1(+)	1(+)	(0)	(0)	1(+)
Potentilla sracilis	(0)	(0)	(0)	6(1)	(0)	2(+)	6(+)	(0)	(0)
Pyrola asarifolia	(0)	(0)	7(10)	(0)	(0)	(0)	4(8)	3(2)	(0)
Pyrola secunda	(0)	1(+)	5(2)	(0)	1(+)	1(+)	4(3)	7(1)	5(3)
Saxifrasa odontoloma	(0)	(0)	3(6)	(0)	(0)	(0)	(0)	7(1)	(0)
Sedum lanceolatum	1(+)	2(+)	(0)	(0)	4(+)	4(+)	(0)	(0)	(0)
Senecio serra	1(+)	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	3(1)
Senecio streptanthifolius	(0)	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Senecio triansularis	(0)	(0)	7(8)	(0)	(0)	(0)	4(1)	10(11)	(0)
Sibbaldia procumbens	(0)	(0)	(0)	8(3)	4(4)	4(1)	(0)	(0)	(0)
Silene menziesii	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	4(1)
Smilacina racemosa	5(+)	3(+)	(0)	(0)	(0)	(0)	(0)	(0)	3(1)
Smilacina stellata	(0)	1(1)	8(2)	(0)	(0)	(0)	4(1)	3(2)	3(1)
Solidaso spathulata	(0)	(0)	(0)	(0)	3(+)	1(2)	(0)	(0)	(0)
Stellaria jamesiana	6(2)	6(1)	(0)	6(+)	1(+)	(0)	4(+)	(0)	4(1)
Streptopus amplexifolius	(0)	(0)	5(1)	(0)	(0)	(0)	2(6)	10(5)	(0)
Thalictrum fendleri	5(2)	5(1)	5(1)	(0)	(0)	(0)	4(2)	3(1)	8(3)
Viola adunca	1(+)	4(+)	2(+)	(0)	1(+)	(0)	4(+)	(0)	4(1)
Viola nuttallii	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Viola purpurea	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(+)

(+) = COVER <0.5%; CODE TO CONSTANCY VALUES: + = 0-5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%, 4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

	ABIES LASIOCARPA SERIES (cont.)									
	PHMA h.t.	ACGL h.t.	VACA h.t.	VAGL h.t.	VASC h.t.			CARU h.t.	PERA h.t.	
					ARLA phase	CAGE phase	VASC phase		PSME phase	PERA phase
Number of Stands	10	22	12	28	28	9	47	17	32	34
TREES										
Abies concolor	2(19)	+(5)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Abies lasiocarpa	10(32)	10(38)	10(22)	10(29)	10(45)	10(38)	10(18)	9(14)	10(34)	10(34)
Picea engelmannii	5(20)	2(13)	8(30)	8(43)	10(35)	9(19)	9(36)	1(1)	6(25)	6(28)
Picea pungens	(0)	(0)	(0)	+(1)	(0)	(0)	(0)	(0)	(0)	(0)
Pinus contorta	1(+)	1(31)	8(47)	4(34)	6(19)	10(33)	8(45)	9(56)	4(27)	7(47)
Pinus flexilis	(0)	+(3)	(0)	+(5)	(0)	(0)	(0)	(0)	(0)	(0)
Pinus ponderosa	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Pseudotsuga menziesii	9(47)	8(34)	2(6)	4(10)	(0)	(0)	+(5)	5(33)	10(26)	(0)
Juniperus scopulorum	(0)	(0)	(0)	+(2)	(0)	(0)	(0)	(0)	(0)	(0)
Populus tremuloides	3(4)	3(23)	3(10)	1(21)	(0)	1(+)	1(3)	6(6)	4(21)	3(7)
Acer grandidentatum	2(2)	3(3)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Quercus gambelii	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
SHRUBS AND SUBSHRUBS										
Acer glabrum	4(12)	6(17)	1(1)	(0)	(0)	(0)	(0)	1(+)	+(1)	(0)
Amelanchier alnifolia	10(12)	7(4)	2(+)	3(3)	(0)	1(+)	(0)	6(3)	5(2)	3(1)
Arctostaphylos patula	(0)	(0)	(0)	+(2)	(0)	(0)	(0)	(0)	(0)	(0)
Arctostaphylos uva-ursi	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Artemisia tridentata	(0)	+(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	+(+)
Berberis repens	8(2)	7(2)	2(1)	2(4)	+(2)	2(+)	1(1)	6(1)	6(2)	1(1)
Ceanothus velutinus	1(10)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(12)	+(4)
Cercocarpus ledifolius	1(2)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Cercocarpus montanus	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Chrysothamnus viscidiflorus	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clematis columbiana	5(12)	1(3)	(0)	(0)	(0)	(0)	(0)	(0)	1(3)	(0)
Clematis pseudoalpina	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	+(+)	(0)
Juniperus communis	(0)	1(3)	8(3)	+(15)	2(1)	3(6)	4(6)	3(1)	(0)	(0)
Lonicera involucrata	3(+)	1(1)	2(+)	2(2)	1(1)	(0)	(0)	1(+)	2(2)	+(+)
Lonicera utahensis	5(5)	3(4)	1(2)	3(2)	1(1)	(0)	+(+)	1(5)	3(1)	2(1)
Pachistima myrsinites	10(13)	9(8)	5(1)	8(2)	5(2)	8(3)	3(1)	8(2)	9(4)	8(2)
Physocarpus malvaceus	10(40)	1(2)	(0)	+(+)	(0)	(0)	(0)	(0)	(0)	(0)
Prunus virginiana	2(1)	3(4)	(0)	(0)	(0)	(0)	(0)	1(+)	1(7)	+(1)
Purshia tridentata	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Ribes cereum	(0)	+(10)	(0)	(0)	(0)	(0)	(0)	1(+)	(0)	(0)
Ribes montigenum	(0)	+(+)	5(5)	4(3)	6(2)	1(1)	4(2)	(0)	(0)	(0)
Ribes viscosissimum	2(6)	3(1)	(0)	3(1)	+(+)	(0)	+(+)	1(+)	4(1)	2(+)
Rosa nutkana	8(1)	5(2)	3(+)	2(1)	1(1)	2(+)	2(1)	7(1)	6(1)	3(1)
Rosa woodsii	(0)	3(1)	(0)	(0)	(0)	(0)	+(+)	1(+)	2(+)	(0)
Rubus parviflorus	5(6)	4(22)	2(+)	4(1)	+(1)	1(+)	(0)	1(1)	3(4)	+(+)
Sambucus cerulea	(0)	+(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Sambucus racemosa	(0)	1(1)	1(+)	1(1)	1(+)	(0)	+(1)	(0)	1(+)	1(31)
Shepherdia canadensis	2(8)	1(1)	2(2)	4(5)	+(+)	(0)	1(1)	2(+)	2(6)	2(3)
Sorbus scopulina	6(12)	8(13)	(0)	6(1)	+(+)	(0)	(0)	1(2)	4(1)	1(1)
Symphoricarpos oreophilus	8(5)	6(4)	2(1)	1(10)	(0)	1(+)	(0)	4(1)	8(3)	3(+)
Vaccinium caespitosum	(0)	(0)	9(3)	(0)	+(+)	1(+)	+(+)	1(+)	(0)	(0)
Vaccinium globulare	(0)	(0)	1(2)	10(42)	+(1)	(0)	(0)	(0)	1(+)	1(2)
Vaccinium scoparium	(0)	(0)	7(18)	1(5)	10(48)	10(37)	10(37)	1(+)	1(+)	+(2)
GRAMINOIDS										
Agropyron spicatum	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Agropyron trachycaulum	(0)	(0)	1(+)	(0)	(0)	(0)	(0)	2(2)	1(+)	1(1)
Bromus anomalus	(0)	1(1)	1(2)	(0)	(0)	(0)	(0)	(0)	+(1)	(0)
Bromus carinatus	1(+)	2(2)	(0)	+(+)	(0)	(0)	+(+)	1(2)	3(1)	1(+)
Bromus ciliatus	3(+)	1(2)	5(2)	1(+)	3(1)	3(1)	1(1)	3(+)	1(1)	1(+)
Calamagrostis canadensis	(0)	(0)	2(+)	(0)	+(1)	(0)	+(+)	(0)	(0)	(0)
Calamagrostis rubescens	(0)	1(23)	(0)	+(+)	(0)	1(25)	(0)	10(33)	+(2)	+(+)
Carex geyeri	3(3)	2(3)	2(23)	1(7)	3(6)	10(20)	1(1)	5(4)	2(8)	+(1)
Carex rossii	(0)	4(2)	7(1)	7(1)	8(1)	7(1)	9(2)	5(1)	6(1)	10(2)
Deschampsia cespitosa	(0)	(0)	(0)	(0)	+(+)	(0)	(0)	(0)	(0)	(0)
Elymus glaucus	(0)	3(1)	1(3)	2(2)	3(1)	6(+)	+(+)	2(2)	3(1)	1(+)
Festuca idahoensis	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Festuca ovina	(0)	(0)	3(1)	(0)	(0)	(0)	3(1)	(0)	(0)	(0)
Leucopoa kingii	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	+(1)	(0)
Luzula spicata	(0)	(0)	(0)	(0)	1(+)	(0)	1(+)	(0)	(0)	(0)
Poa fendleriana	(0)	(0)	1(+)	(0)	1(1)	1(+)	1(1)	(0)	(0)	(0)
Poa nervosa	1(1)	1(1)	5(1)	2(1)	6(1)	9(2)	6(1)	6(+)	3(2)	4(1)
Sitanion hystrix	(0)	(0)	1(+)	(0)	(0)	(0)	+(+)	(0)	(0)	(0)
Trisetum spicatum	(0)	1(+)	8(1)	1(+)	7(+)	7(1)	5(1)	1(+)	2(+)	2(+)

(+) = COVER <0.5%; CODE TO CONSTANCY VALUES: + = 0-5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%, 4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

	ABIES LASIOCARPA SERIES (cont.)									
	PHMA h.t.	ACGL h.t.	VACA h.t.	VAGL h.t.	VASC h.t.			CARU h.t.	PERA h.t.	
					ARLA phase	CAGE phase	VASC phase		PSME phase	PERA phase
Number of Stands	10	22	12	28	28	9	47	17	32	34
FORBS AND FERN ALLIES										
Achillea millefolium	1(+)	+(+)	5(3)	2(1)	5(1)	4(4)	5(2)	2(+)	2(1)	4(2)
Aconitum columbianum	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Actaea rubra	4(1)	1(1)	(0)	+(+)	(0)	(0)	(0)	(0)	1(1)	(0)
Antennaria microphylla	(0)	+(+)	3(+)	1(1)	3(1)	7(1)	3(1)	1(1)	+(+)	+(+)
Antennaria parvifolia	(0)	+(+)	(0)	(0)	(0)	(0)	1(2)	(0)	(0)	(0)
Aquilegia coerulea	4(1)	5(+)	3(1)	6(1)	1(+)	2(1)	1(1)	1(+)	5(1)	3(1)
Arnica cordifolia	5(4)	7(4)	5(5)	7(3)	6(4)	9(3)	8(3)	9(4)	9(5)	6(4)
Arnica latifolia	(0)	1(2)	3(6)	6(16)	10(9)	2(+)	1(+)	(0)	1(4)	1(9)
Aster engelmannii	8(1)	7(1)	1(2)	6(2)	4(1)	4(1)	+(+)	2(+)	8(2)	6(2)
Aster glaucodes	1(+)	+(+)	1(+)	(0)	(0)	(0)	+(+)	(0)	(0)	(0)
Aster perelegans	(0)	+(+)	(0)	+(15)	(0)	(0)	(0)	1(+)	(0)	(0)
Astragalus miser	(0)	(0)	(0)	(0)	(0)	1(+)	+(+)	1(+)	(0)	(0)
Balsamorhiza sagittata	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	+(+)	(0)
Caltha leptosepala	(0)	(0)	(0)	(0)	1(+)	(0)	+(2)	(0)	(0)	(0)
Castilleja linariaefolia	(0)	(0)	1(+)	+(+)	1(+)	(0)	(0)	1(+)	+(+)	+(+)
Castilleja miniata	(0)	(0)	(0)	(0)	1(+)	(0)	+(+)	(0)	(0)	(0)
Delphinium occidentale	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Disporum trachycarpum	4(+)	4(1)	(0)	+(+)	(0)	(0)	(0)	1(1)	+(+)	(0)
Epilobium angustifolium	3(1)	1(+)	6(1)	3(1)	6(1)	6(1)	4(1)	1(+)	2(1)	1(1)
Equisetum arvense	(0)	+(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Erigeron peregrinus	(0)	(0)	3(2)	4(1)	6(2)	1(+)	2(1)	2(1)	1(+)	2(1)
Erigeron speciosus	(0)	(0)	1(+)	1(1)	1(2)	1(2)	(0)	(0)	1(2)	(0)
Fragaria vesca	8(1)	5(1)	(0)	3(1)	(0)	2(2)	(0)	3(1)	4(2)	3(+)
Fragaria virginiana	(0)	+(+)	6(2)	+(4)	3(1)	1(+)	5(1)	3(+)	2(1)	1(1)
Frasera speciosa	2(+)	1(+)	(0)	1(+)	(0)	(0)	(0)	1(+)	1(+)	1(1)
Galium boreale	(0)	+(1)	4(1)	1(8)	+(1)	3(5)	1(4)	3(+)	+(+)	+(5)
Geranium richardsonii	(0)	2(+)	3(6)	1(+)	2(1)	1(15)	2(1)	2(1)	1(1)	1(+)
Geranium viscosissimum	3(1)	1(+)	3(1)	3(+)	1(3)	2(+)	1(1)	2(+)	4(+)	5(1)
Haplopappus parryi	(0)	(0)	(0)	(0)	+(5)	(0)	2(2)	(0)	(0)	(0)
Hieracium albiflorum	1(+)	3(+)	2(+)	3(1)	1(1)	3(1)	1(1)	7(1)	3(1)	4(2)
Hieracium gracile	(0)	(0)	(0)	(0)	4(1)	3(+)	2(1)	(0)	(0)	(0)
Lathyrus lanszwertii	2(1)	1(4)	2(1)	+(+)	+(+)	2(19)	+(4)	(0)	2(19)	3(21)
Lathyrus pauciflorus	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	+(1)	+(1)
Ligusticum filicinum	(0)	(0)	1(2)	3(1)	3(1)	(0)	(0)	(0)	1(1)	1(3)
Lomatium nuttallii	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Lupinus argenteus	(0)	(0)	4(1)	(0)	1(2)	(0)	2(2)	(0)	(0)	(0)
Mertensia ciliata	1(+)	+(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	+(+)
Mitella pentandra	(0)	(0)	(0)	(0)	+(+)	(0)	(0)	(0)	(0)	(0)
Mitella stauropetala	9(3)	7(1)	2(2)	4(1)	1(1)	1(+)	(0)	2(+)	3(1)	1(1)
Osmorhiza chilensis	7(1)	8(7)	1(+)	5(2)	1(1)	(0)	(0)	4(1)	7(2)	6(1)
Osmorhiza depauperata	1(1)	1(4)	3(6)	5(3)	4(2)	3(6)	1(1)	6(1)	2(3)	4(2)
Pedicularis racemosa	1(1)	3(1)	3(2)	9(7)	8(4)	7(2)	2(3)	1(5)	10(4)	10(6)
Penstemon whippleanus	(0)	(0)	(0)	+(+)	2(+)	1(+)	1(+)	(0)	(0)	(0)
Polemonium foliosissimum	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(+)
Polemonium pulcherrimum	(0)	(0)	1(+)	(0)	1(2)	(0)	2(1)	(0)	(0)	(0)
Polygonum bistortoides	(0)	(0)	2(1)	(0)	1(+)	(0)	2(1)	(0)	(0)	+(2)
Potentilla glandulosa	(0)	+(+)	(0)	1(1)	+(+)	(0)	(0)	(0)	1(1)	2(+)
Potentilla gracilis	(0)	(0)	4(1)	+(+)	+(+)	2(1)	1(+)	1(1)	+(+)	1(1)
Pyrola asarifolia	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Pyrola secunda	8(1)	6(2)	7(4)	9(1)	5(2)	3(2)	2(1)	4(1)	7(1)	5(1)
Saxifraga odontoloma	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Sedum lanceolatum	(0)	(0)	(0)	(0)	1(+)	2(1)	1(1)	(0)	(0)	+(+)
Senecio serra	(0)	2(+)	(0)	(0)	(0)	(0)	(0)	1(+)	1(+)	+(+)
Senecio streptanthifolius	(0)	+(+)	(0)	(0)	(0)	(0)	(0)	(0)	1(1)	1(+)
Senecio triangularis	(0)	(0)	(0)	(0)	+(1)	(0)	(0)	(0)	(0)	(0)
Sibbaldia procumbens	(0)	(0)	1(15)	(0)	+(+)	1(+)	1(1)	(0)	(0)	(0)
Silene menziesii	1(+)	5(1)	(0)	1(1)	(0)	(0)	(0)	2(2)	2(+)	1(1)
Smilacina racemosa	3(1)	4(+)	1(+)	(0)	(0)	(0)	+(+)	(0)	1(2)	(0)
Smilacina stellata	1(+)	1(1)	(0)	+(2)	(0)	(0)	(0)	1(+)	(0)	+(2)
Solidago spathulata	(0)	(0)	1(2)	(0)	1(+)	(0)	2(1)	1(+)	(0)	(0)
Stellaria jamesiana	(0)	3(1)	4(1)	3(3)	3(1)	9(1)	3(1)	4(1)	5(2)	6(2)
Streptopus amplexifolius	(0)	(0)	(0)	(0)	+(+)	(0)	(0)	(0)	(0)	(0)
Thalictrum fendleri	7(1)	8(4)	3(1)	5(1)	+(2)	1(2)	(0)	5(+)	7(4)	3(1)
Viola adunca	7(1)	3(+)	2(1)	1(1)	+(+)	2(+)	+(+)	5(1)	3(1)	2(1)
Viola nuttallii	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(1)	1(1)
Viola purpurea	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(+)

(+) = COVER <0.5%; CODE TO CONSTANCY VALUES: + = 0-5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%, 4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

	ABIES LASIOCARPA SERIES (cont.)									
	BERE h.t.						RIMO h.t.			
	PIFL phase	RIMO phase	CAGE phase	JUCO phase	PSME phase	BERE phase	TRSP phase	PICO phase	THFE phase	RIMO phase
Number of Stands	19	58	17	15	73	32	18	8	29	22
TREES										
Abies concolor	(0)	(0)	(0)	(0)	1(43)	+(17)	(0)	(0)	(0)	(0)
Abies lasiocarpa	10(17)	10(42)	9(36)	9(27)	10(34)	10(35)	9(25)	9(9)	10(56)	10(34)
Picea engelmannii	4(10)	8(35)	3(30)	3(5)	3(20)	5(25)	8(25)	10(22)	7(38)	7(32)
Picea pungens	(0)	+(13)	1(41)	3(33)	+(39)	(0)	(0)	(0)	(0)	(0)
Pinus contorta	2(8)	2(14)	6(34)	9(39)	3(40)	7(40)	1(4)	10(17)	+(24)	(0)
Pinus flexilis	10(19)	1(3)	1(2)	1(2)	1(2)	(0)	(0)	(0)	1(2)	+(3)
Pinus ponderosa	(0)	(0)	1(2)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Pseudotsuga menziesii	8(34)	4(41)	5(31)	5(19)	10(31)	(0)	(0)	(0)	2(8)	2(35)
Juniperus scopulorum	(0)	(0)	1(3)	(0)	+(+)	(0)	(0)	(0)	(0)	(0)
Populus tremuloides	1(3)	3(10)	10(18)	8(18)	6(15)	8(20)	1(1)	3(44)	3(28)	1(3)
Acer grandidentatum	1(5)	(0)	1(1)	(0)	1(21)	(0)	(0)	(0)	(0)	(0)
Quercus gambelii	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
SHRUBS AND SUBSHRUBS										
Acer glabrum	(0)	1(1)	(0)	1(2)	+(1)	+(2)	(0)	(0)	(0)	(0)
Amelanchier alnifolia	3(2)	1(1)	4(2)	2(1)	5(5)	4(3)	(0)	(0)	(0)	1(+)
Arctostaphylos patula	(0)	(0)	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Arctostaphylos uva-ursi	(0)	(0)	1(+)	3(1)	(0)	+(+)	(0)	(0)	(0)	(0)
Artemisia tridentata	3(1)	1(2)	1(1)	1(+)	+(1)	1(1)	(0)	(0)	(0)	+(+)
Berberis repens	5(3)	3(1)	8(4)	7(2)	7(3)	4(1)	(0)	(0)	(0)	(0)
Ceanothus velutinus	1(3)	+(+)	1(1)	(0)	+(1)	1(+)	(0)	(0)	(0)	(0)
Cercocarpus ledifolius	1(3)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Cercocarpus montanus	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Chrysothamnus viscidiflorus	(0)	(0)	(0)	1(+)	+(+)	+(1)	(0)	(0)	(0)	(0)
Clematis columbiana	(0)	(0)	1(+)	(0)	1(+)	(0)	(0)	(0)	(0)	(0)
Clematis pseudoalpina	(0)	+(13)	(0)	1(2)	1(2)	1(+)	(0)	(0)	(0)	(0)
Juniperus communis	3(11)	1(7)	5(14)	10(14)	1(2)	1(2)	1(3)	4(2)	(0)	(0)
Lonicera involucrata	(0)	+(2)	(0)	1(1)	1(1)	(0)	(0)	(0)	1(1)	(0)
Lonicera utahensis	1(1)	4(2)	(0)	(0)	2(2)	1(1)	(0)	(0)	2(2)	1(3)
Pachistima myrsinites	8(5)	10(4)	7(4)	6(4)	9(9)	9(3)	(0)	(0)	(0)	(0)
Physocarpus malvaceus	(0)	(0)	(0)	(0)	+(1)	(0)	(0)	(0)	(0)	(0)
Prunus virginiana	2(14)	+(3)	2(15)	1(+)	2(7)	1(3)	(0)	(0)	(0)	(0)
Purshia tridentata	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Ribes cereum	2(4)	+(5)	1(2)	1(+)	+(1)	(0)	(0)	(0)	(0)	(0)
Ribes montigenum	4(7)	9(6)	(0)	(0)	(0)	(0)	9(2)	10(1)	10(18)	10(11)
Ribes viscosissimum	1(+)	1(1)	(0)	2(+)	2(2)	1(1)	(0)	(0)	+(+)	+(+)
Rosa nutkana	4(1)	3(1)	7(2)	7(5)	5(1)	5(1)	(0)	(0)	(0)	1(1)
Rosa woodsii	2(1)	1(1)	1(+)	1(2)	1(1)	1(1)	(0)	(0)	(0)	(0)
Rubus parviflorus	1(+)	1(1)	(0)	1(+)	1(1)	1(+)	(0)	(0)	(0)	(0)
Sambucus cerulea	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	+(+)	(0)
Sambucus racemosa	1(+)	2(2)	(0)	(0)	+(1)	1(10)	1(+)	(0)	5(4)	1(2)
Shepherdia canadensis	4(3)	1(3)	1(1)	4(5)	2(3)	1(2)	(0)	(0)	(0)	(0)
Sorbus scopulina	3(+)	1(1)	(0)	1(+)	2(1)	1(1)	(0)	(0)	2(+)	1(+)
Symphoricarpos oreophilus	9(7)	5(2)	7(5)	5(3)	8(5)	6(8)	(0)	(0)	4(4)	4(2)
Vaccinium caespitosum	(0)	(0)	(0)	1(+)	(0)	(0)	2(+)	1(+)	(0)	(0)
Vaccinium globulare	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(3)
Vaccinium scoparium	(0)	1(4)	(0)	1(2)	+(+)	1(2)	5(1)	3(1)	(0)	1(3)
GRAMINOIDS										
Agropyron spicatum	1(+)	(0)	(0)	(0)	+(4)	(0)	(0)	(0)	(0)	(0)
Agropyron trachycaulum	4(1)	1(6)	2(2)	3(1)	2(3)	2(3)	2(+)	1(5)	1(+)	+(+)
Bromus anomalus	1(1)	(0)	1(2)	(0)	+(7)	+(+)	(0)	(0)	(0)	(0)
Bromus carinatus	3(1)	2(1)	1(3)	(0)	2(1)	1(1)	(0)	(0)	3(2)	2(+)
Bromus ciliatus	(0)	1(3)	4(1)	6(1)	1(1)	1(1)	1(+)	3(+)	1(5)	(0)
Calamagrostis canadensis	(0)	(0)	(0)	(0)	+(+)	(0)	(0)	(0)	(0)	(0)
Calamagrostis rubescens	(0)	1(1)	1(1)	(0)	1(1)	+(+)	(0)	(0)	(0)	(0)
Carex geyeri	1(+)	2(6)	10(23)	4(1)	2(1)	3(1)	(0)	(0)	1(2)	1(1)
Carex rossii	3(+)	5(1)	1(2)	7(3)	5(1)	7(2)	6(1)	10(1)	4(3)	5(+)
Deschampsia cespitosa	(0)	(0)	(0)	1(+)	(0)	(0)	2(5)	(0)	(0)	(0)
Elymus glaucus	1(+)	1(2)	2(2)	1(+)	2(2)	2(4)	(0)	(0)	2(4)	(0)
Festuca idahoensis	(0)	(0)	(0)	(0)	+(+)	+(+)	(0)	(0)	+(+)	(0)
Festuca ovina	(0)	1(1)	(0)	3(1)	+(2)	(0)	6(1)	5(1)	(0)	+(+)
Leucopoa kingii	5(2)	1(4)	(0)	1(+)	+(+)	(0)	(0)	(0)	(0)	1(+)
Luzula spicata	(0)	(0)	(0)	(0)	(0)	(0)	3(+)	(0)	(0)	+(+)
Poa fendleriana	(0)	+(5)	1(3)	(0)	(0)	(0)	2(+)	(0)	(0)	(0)
Poa nervosa	4(1)	3(1)	4(3)	7(1)	2(1)	5(3)	7(2)	10(1)	2(7)	3(1)
Sitanion hystrix	1(+)	(0)	1(+)	1(2)	(0)	+(2)	1(+)	1(+)	(0)	(0)
Trisetum spicatum	1(+)	2(1)	2(1)	5(3)	1(1)	3(1)	10(1)	10(1)	1(1)	1(1)

(+) = COVER <0.5%; CODE TO CONSTANCY VALUES: + = 0-5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%, 4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

	ABIES LASIOCARPA SERIES (cont.)									
	BERE h.t.						RIMO h.t.			
	PIFL phase	RIMO phase	CAGE phase	JUCO phase	PSME phase	BERE phase	TRSP phase	PICO phase	THFE phase	RIMO phase
Number of stands	19	58	17	15	73	32	18	8	29	22
FORBS AND FERN ALLIES										
Achillea millefolium	7(1)	3(3)	4(3)	7(2)	1(1)	4(1)	6(1)	9(1)	4(1)	4(1)
Aconitum columbianum	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	+(10)	(0)
Actaea rubra	(0)	+(1)	(0)	(0)	+(1)	+(2)	(0)	(0)	+(4)	(0)
Antennaria microphylla	1(1)	+(+)	2(1)	5(1)	+(+)	1(+)	6(+)	8(+)	(0)	(0)
Antennaria parvifolia	(0)	+(+)	1(+)	2(1)	(0)	(0)	(0)	(0)	(0)	(0)
Aquilegia coerulea	3(+)	6(2)	6(3)	5(1)	4(2)	3(2)	4(1)	1(1)	6(3)	8(1)
Arnica cordifolia	4(3)	7(5)	6(5)	6(6)	6(5)	6(2)	2(+)	4(1)	3(3)	3(6)
Arnica latifolia	(0)	3(7)	(0)	(0)	(0)	(0)	3(1)	1(+)	1(5)	4(12)
Aster engelmannii	4(2)	4(4)	1(1)	(0)	5(1)	4(2)	(0)	(0)	5(3)	6(1)
Aster glaucodes	2(1)	+(+)	1(+)	1(+)	+(1)	(0)	(0)	(0)	(0)	(0)
Aster perelegans	2(1)	(0)	1(5)	(0)	1(1)	+(2)	(0)	(0)	(0)	(0)
Astragalus miser	1(+)	1(6)	4(2)	6(7)	+(1)	+(+)	(0)	(0)	(0)	(0)
Balsamorhiza sagittata	1(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Caltha leptosepala	(0)	+(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	+(+)
Castilleja linariaefolia	(0)	+(+)	(0)	1(5)	(0)	+(+)	(0)	(0)	(0)	1(1)
Castilleja minitata	1(+)	(0)	(0)	1(+)	+(+)	(0)	(0)	(0)	+(2)	(0)
Delphinium occidentale	(0)	(0)	(0)	(0)	+(+)	(0)	(0)	(0)	1(+)	1(1)
Disporum trachycarpum	(0)	+(+)	1(+)	(0)	1(1)	+(+)	(0)	(0)	(0)	(0)
Epilobium angustifolium	1(+)	2(2)	2(+)	4(1)	1(1)	1(1)	1(+)	3(+)	2(1)	2(1)
Equisetum arvense	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Erigeron peregrinus	1(1)	2(1)	1(+)	4(2)	(0)	+(+)	3(1)	1(3)	1(2)	4(1)
Erigeron speciosus	4(1)	1(9)	2(1)	2(6)	1(1)	2(1)	(0)	(0)	1(1)	1(2)
Fragaria vesca	1(3)	2(2)	2(2)	(0)	3(2)	4(1)	(0)	1(+)	1(+)	(0)
Fragaria virginiana	(0)	1(1)	6(2)	3(2)	1(1)	1(1)	2(1)	8(1)	+(1)	(0)
Frasera speciosa	4(1)	2(1)	2(1)	4(1)	2(1)	1(1)	1(+)	(0)	1(1)	3(+)
Galium boreale	1(1)	1(1)	7(1)	5(4)	2(+)	2(+)	(0)	(0)	+(2)	1(+)
Geranium richardsonii	(0)	1(6)	2(1)	3(5)	+(+)	2(1)	(0)	1(3)	+(2)	+(+)
Geranium viscosissimum	6(1)	3(2)	3(1)	3(1)	3(1)	3(1)	(0)	1(1)	2(9)	3(1)
Haplopappus parryi	(0)	1(+)	1(1)	1(+)	+(1)	1(2)	1(+)	(0)	1(9)	(0)
Hieracium albiflorum	(0)	1(+)	2(+)	(0)	1(1)	4(1)	1(+)	(0)	+(+)	1(+)
Hieracium gracile	(0)	(0)	(0)	1(+)	(0)	(0)	1(+)	(0)	(0)	(0)
Lathyrus lanszwertii	2(3)	2(6)	2(12)	1(20)	2(7)	2(1)	(0)	(0)	4(17)	3(20)
Lathyrus pauciflorus	(0)	+(2)	1(2)	(0)	(0)	(0)	(0)	(0)	+(+)	(0)
Ligusticum filicinum	1(2)	2(+)	(0)	(0)	+(+)	(0)	(0)	(0)	2(1)	4(+)
Lomatium nuttallii	4(7)	+(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(1)
Lupinus argenteus	1(1)	1(4)	1(+)	3(5)	+(1)	+(+)	1(2)	10(7)	1(1)	1(1)
Mertensia ciliata	1(+)	1(1)	(0)	(0)	+(+)	(0)	3(+)	(0)	3(4)	3(2)
Mitella pentandra	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Mitella stauropetala	1(+)	2(1)	2(2)	(0)	3(2)	1(1)	(0)	(0)	3(1)	2(2)
Osmorhiza chilensis	4(1)	4(1)	3(4)	1(1)	6(3)	3(1)	1(+)	1(+)	4(3)	6(6)
Osmorhiza depauperata	2(2)	3(7)	4(2)	2(1)	2(2)	4(1)	1(+)	3(+)	4(8)	3(2)
Pedicularis racemosa	3(3)	4(6)	(0)	1(+)	(0)	+(+)	2(1)	(0)	2(5)	5(4)
Penstemon whippleanus	1(+)	1(+)	(0)	1(+)	(0)	(0)	4(+)	1(+)	(0)	(0)
Polemonium foliosissimum	(0)	1(+)	1(+)	(0)	+(+)	+(2)	(0)	(0)	2(1)	+(+)
Polemonium pulcherrimum	(0)	(0)	(0)	(0)	+(15)	(0)	3(1)	(0)	1(4)	1([illegible])
Polygonum bistortoides	(0)	+(1)	(0)	1(1)	(0)	(0)	1(+)	(0)	(0)	(0)
Potentilla glandulosa	1(+)	2(+)	(0)	1(+)	1(+)	(0)	(0)	(0)	2(1)	3(1)
Potentilla gracilis	(0)	+(+)	2(1)	4(1)	+(+)	+(2)	2(+)	8(+)	+(+)	+(+)
Pyrola asarifolia	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Pyrola secunda	1(1)	6(2)	4(3)	5(3)	4(2)	5(1)	2(1)	1(+)	2(4)	3(1)
Saxifraga odontoloma	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	+(1)	(0)
Sedum lanceolatum	2(+)	(0)	(0)	1(+)	+(+)	1(+)	4(+)	6(+)	+(+)	(0)
Senecio serra	(0)	+(+)	1(1)	(0)	1(1)	2(1)	(0)	(0)	1(8)	1(1)
Senecio streptanthifolius	3(+)	2(+)	1(1)	1(+)	1(+)	1(1)	1(+)	(0)	1(+)	1(+)
Senecio triangularis	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Sibbaldia procumbens	(0)	(0)	(0)	(0)	(0)	(0)	5(+)	1(+)	(0)	(0)
Silene menziesii	2(1)	1(+)	1(2)	(0)	2(1)	1(1)	(0)	(0)	1(1)	(0)
Smilacina racemosa	1(+)	+(1)	1(2)	(0)	2(1)	(0)	(0)	(0)	1(+)	+(+)
Smilacina stellata	2(1)	+(1)	4(2)	3(+)	1(1)	+(+)	(0)	1(+)	(0)	(0)
Solidago spathulata	1(1)	1(1)	1(1)	4(1)	+(2)	2(+)	5(1)	8(1)	+(1)	+(2)
Stellaria jamesiana	6(1)	4(2)	5(2)	4(3)	5(1)	5(1)	2(1)	1(+)	7(2)	8(3)
Streptopus amplexifolius	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Thalictrum fendleri	6(5)	6(2)	7(7)	5(4)	7(2)	6(1)	(0)	(0)	10(4)	(0)
Viola adunca	1(1)	1(1)	5(1)	2(1)	4(1)	3(1)	(0)	(0)	2(4)	1(2)
Viola nuttallii	1(2)	1(1)	1(1)	(0)	1(+)	1(1)	(0)	(0)	2(3)	1(2)
Viola purpurea	1(2)	1(1)	(0)	(0)	+(1)	1(1)	(0)	(0)	(0)	+(2)

(+) = COVER <0.5%; CODE TO CONSTANCY VALUES: + = 0-5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%,
4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

	ABIES LASIOCARPA SERIES (cont.)		PINUS CONTORTA SERIES						
	OSCH h.t.	JUCO h.t.	CACA c.t.	VACA c.t.	VASC c.t.	JUCO c.t.	ARUV h.t.	BERE c.t.	CARO h.t.
Number of Stands	12	12	9	29	18	14	24	20	8
TREES									
Abies concolor	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(1)	(0)
Abies lasiocarpa	10(25)	8(12)	4(+)	2(1)	6(1)	4(1)	1(1)	3(+)	(0)
Picea engelmannii	2(8)	9(12)	3(1)	2(1)	4(1)	2(1)	(0)	(0)	(0)
Picea pungens	(0)	(0)	1(+)	+(1)	1(+)	(0)	(0)	(0)	(0)
Pinus contorta	(0)	10(30)	10(67)	10(67)	10(63)	10(69)	10(56)	10(61)	10(63)
Pinus flexilis	(0)	(0)	(0)	(0)	(0)	(0)	+(+)	(0)	(0)
Pinus ponderosa	(0)	(0)	(0)	(0)	(0)	(0)	+(+)	(0)	(0)
Pseudotsuga menziesii	(0)	1(30)	(0)	(0)	(0)	2(1)	+(+)	1(2)	(0)
Juniperus scopulorum	(0)	(0)	(0)	+(+)	(0)	(0)	(0)	1(+)	(0)
Populus tremuloides	10(63)	6(6)	2(11)	3(8)	4(15)	6(5)	5(6)	6(7)	(0)
Acer grandidentatum	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Quercus gambelii	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
SHRUBS AND SUBSHRUBS									
Acer glabrum	(0)	1(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Amelanchier alnifolia	1(6)	2(1)	(0)	1(5)	1(+)	4(+)	1(+)	3(1)	(0)
Arctostaphylos patula	(0)	(0)	(0)	+(+)	(0)	4(8)	(0)	1(30)	(0)
Arctostaphylos uva-ursi	(0)	(0)	1(+)	3(4)	(0)	2(+)	10(6)	2(+)	(0)
Artemisia tridentata	1(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Berberis repens	(0)	(0)	(0)	3(2)	4(1)	7(1)	7(1)	9(1)	(0)
Ceanothus velutinus	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(2)	(0)
Cercocarpus ledifolius	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Cercocarpus montanus	(0)	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Chrysothamnus viscidiflorus	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clematis columbiana	1(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Clematis pseudoalpina	(0)	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Juniperus communis	(0)	8(3)	6(1)	10(3)	7(1)	7(2)	8(4)	9(5)	6(1)
Lonicera involucrata	(0)	1(+)	(0)	1(1)	1(+)	(0)	(0)	(0)	(0)
Lonicera utahensis	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Pachistima myrsinites	(0)	(0)	2(1)	3(5)	6(1)	4(+)	2(1)	4(+)	(0)
Physocarpus malvaceus	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Prunus virginiana	(0)	(0)	(0)	(0)	(0)	(0)	(0)	1(1)	(0)
Purshia tridentata	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Ribes cereum	(0)	(0)	(0)	(0)	(0)	(0)	+(+)	(0)	(0)
Ribes montigenum	(0)	(0)	2(1)	1(3)	2(1)	(0)	+(+)	(0)	3(+)
Ribes viscosissimum	1(1)	(0)	(0)	1(+)	1(+)	2(+)	2(+)	1(+)	(0)
Rosa nutkana	1(+)	2(2)	6(1)	3(2)	3(1)	3(1)	3(1)	5(1)	3(1)
Rosa woodsii	(0)	(0)	(0)	1(1)	1(+)	1(+)	2(1)	2(+)	(0)
Rubus parviflorus	1(1)	(0)	(0)	+(50)	1(+)	1(+)	(0)	1(+)	(0)
Sambucus cerulea	(0)	(0)	(0)	(0)	(0)	(0)	+(+)	(0)	(0)
Sambucus racemosa	3(3)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Shepherdia canadensis	(0)	1(30)	(0)	3(3)	3(1)	1(1)	3(+)	2(+)	(0)
Sorbus scopulina	1(2)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Symphoricarpos oreophilus	6(14)	1(+)	1(1)	1(+)	(0)	3(+)	1(+)	2(+)	(0)
Vaccinium caespitosum	(0)	3(+)	7(8)	10(7)	1(+)	(0)	1(+)	2(+)	3(+)
Vaccinium globulare	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Vaccinium scoparium	(0)	4(2)	6(1)	5(5)	10(35)	1(+)	+(+)	(0)	1(+)
GRAMINOIDS									
Agropyron spicatum	(0)	(0)	(0)	(0)	(0)	1(+)	(0)	(0)	(0)
Agropyron trachycaulum	3(5)	(0)	1(+)	+(+)	(0)	(0)	(0)	(0)	3(+)
Bromus anomalus	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Bromus carinatus	7(6)	(0)	(0)	+(+)	(0)	(0)	(0)	1(+)	(0)
Bromus ciliatus	(0)	3(+)	2(6)	2(1)	2(+)	6(+)	+(1)	3(+)	(0)
Calamagrostis canadensis	(0)	(0)	10(32)	3(1)	1(+)	(0)	(0)	(0)	1(+)
Calamagrostis rubescens	(0)	(0)	(0)	(0)	1(70)	(0)	(0)	(0)	(0)
Carex geyeri	1(+)	(0)	1(+)	2(2)	3(2)	(0)	1(7)	7(19)	(0)
Carex rossii	3(1)	9(1)	3(1)	8(1)	6(1)	9(+)	7(1)	6(1)	10(+)
Deschampsia cespitosa	(0)	(0)	2(7)	1(5)	(0)	(0)	(0)	(0)	(0)
Elymus glaucus	6(7)	(0)	1(15)	2(12)	(0)	(0)	(0)	(0)	(0)
Festuca idahoensis	1(2)	1(+)	(0)	2(4)	(0)	3(1)	1(1)	(0)	(0)
Festuca ovina	(0)	3(1)	1(1)	3(+)	2(+)	1(1)	3(2)	1(+)	(0)
Leucopoa kingii	(0)	(0)	(0)	+(+)	(0)	(0)	(0)	(0)	(0)
Luzula spicata	(0)	(0)	2(+)	3(+)	1(+)	(0)	(0)	(0)	(0)
Poa fendleriana	(0)	(0)	(0)	+(+)	(0)	1(1)	1(1)	(0)	(0)
Poa nervosa	3(2)	9(2)	6(2)	8(2)	6(1)	4(1)	7(2)	9(1)	9(3)
Sitanion hystrix	(0)	3(+)	1(+)	2(1)	(0)	1(+)	2(+)	1(+)	4(+)
Trisetum spicatum	1(+)	8(1)	8(1)	8(1)	6(+)	2(+)	4(1)	5(1)	5(+)

(+) = COVER <0.5%; CODE TO CONSTANCY VALUES: + = 0-5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%, 4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

	ABIES LASIOCARPA SERIES (cont.)		PINUS CONTORTA SERIES						
	OSCH h.t.	JUCO h.t.	CACA c.t.	VACA c.t.	VASC c.t.	JUCO c.t.	ARUV h.t.	BERE c.t.	CARO h.t.
Number of Stands	12	12	9	29	18	14	24	20	8
FORBS AND FERN ALLIES									
Achillea millefolium	6(1)	3(1)	10(1)	6(1)	4(+)	1(1)	2(1)	5(+)	5(1)
Aconitum columbianum	(0)	(0)	(0)	+(2)	(0)	(0)	(0)	(0)	(0)
Actaea rubra	2(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Antennaria microphylla	(0)	8(+)	7(+)	7(1)	5(+)	3(+)	5(1)	7(1)	6(+)
Antennaria parvifolia	(0)	(0)	(0)	1(1)	(0)	(0)	1(+)	(0)	(0)
Aquilegia coerulea	5(1)	1(+)	1(+)	3(1)	1(+)	1(3)	1(2)	2(+)	(0)
Arnica cordifolia	3(1)	4(1)	7(3)	8(2)	8(2)	3(2)	5(3)	5(1)	9(1)
Arnica latifolia	(0)	(0)	(0)	(0)	(0)	1(+)	(0)	(0)	(0)
Aster engelmannii	6(3)	(0)	(0)	+(+)	(0)	(0)	(0)	1(+)	(0)
Aster glaucodes	(0)	(0)	(0)	+(+)	(0)	4(1)	2(1)	1(1)	(0)
Aster perelegans	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Astragalus miser	(0)	(0)	(0)	1(+)	(0)	(0)	5(3)	4(6)	5(11)
Balsamorhiza sagittata	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Caltha leptosepala	(0)	(0)	(0)	1(1)	(0)	(0)	(0)	(0)	(0)
Castilleja linariaefolia	(0)	(0)	1(+)	1(1)	1(+)	(0)	1(+)	1(+)	(0)
Castilleja miniata	(0)	(0)	1(1)	+(+)	(0)	(0)	(0)	1(+)	(0)
Delphinium occidentale	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Disporum trachycarpum	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Epilobium angustifolium	1(+)	5(+)	4(+)	5(+)	4(+)	4(+)	4(+)	3(+)	8(+)
Equisetum arvense	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Erigeron peregrinus	(0)	2(1)	4(2)	3(2)	1(2)	1(2)	(0)	3(1)	1(+)
Erigeron speciosus	2(2)	(0)	(0)	1(9)	(0)	(0)	(0)	1(+)	(0)
Fragaria vesca	3(1)	(0)	(0)	+(+)	(0)	(0)	+(+)	(0)	(0)
Fragaria virginiana	(0)	7(1)	10(3)	9(1)	5(1)	1(+)	2(+)	4(1)	8(+)
Frasera speciosa	1(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Galium boreale	(0)	(0)	8(1)	4(2)	2(1)	1(+)	1(1)	4(+)	1(+)
Geranium richardsonii	(0)	(0)	4(2)	3(4)	1(1)	1(1)	(0)	2(1)	1(+)
Geranium viscosissimum	3(2)	1(+)	4(1)	2(2)	2(+)	1(25)	2(1)	3(+)	3(+)
Haplopappus parryi	(0)	1(2)	(0)	+(2)	(0)	1(30)	(0)	(0)	(0)
Hieracium albiflorum	(0)	(0)	(0)	2(1)	3(+)	1(+)	2(+)	2(1)	(0)
Hieracium gracile	(0)	(0)	1(+)	1(+)	2(+)	(0)	(0)	(0)	(0)
Lathyrus lanszwertii	7(27)	(0)	(0)	1(1)	1(4)	(0)	+(2)	1(2)	(0)
Lathyrus pauciflorus	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Ligusticum filicinum	(0)	(0)	(0)	+(+)	(0)	(0)	(0)	(0)	(0)
Lomatium nuttallii	1(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Lupinus argenteus	(0)	6(2)	4(+)	2(1)	4(1)	3(5)	3(6)	4(3)	8(1)
Mertensia ciliata	(0)	(0)	1(1)	(0)	(0)	(0)	(0)	(0)	(0)
Mitella pentandra	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Mitella stauropetala	2(+)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Osmorhiza chilensis	9(5)	1(+)	2(+)	1(2)	2(+)	1(+)	(0)	1(+)	(0)
Osmorhiza depauperata	1(4)	(0)	3(+)	4(+)	2(+)	1(+)	+(+)	3(+)	1(+)
Pedicularis racemosa	(0)	(0)	1(+)	(0)	1(1)	(0)	(0)	(0)	(0)
Penstemon whippleanus	(0)	3(+)	1(+)	1(+)	1(+)	(0)	+(+)	(0)	(0)
Polemonium foliosissimum	2(2)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Polemonium pulcherrimum	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Polygonum bistortoides	(0)	1(+)	3(+)	2(1)	(0)	(0)	(0)	(0)	(0)
Potentilla glandulosa	1(1)	(0)	1(+)	+(+)	(0)	(0)	(0)	1(+)	(0)
Potentilla gracilis	(0)	3(+)	6(+)	3(+)	2(+)	(0)	+(1)	3(+)	5(+)
Pyrola asarifolia	(0)	(0)	(0)	+(3)	(0)	(0)	(0)	(0)	(0)
Pyrola secunda	(0)	2(3)	1(1)	3(1)	3(1)	1(+)	2(+)	3(+)	1(+)
Saxifraga odontoloma	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Sedum lanceolatum	(0)	5(+)	(0)	3(+)	2(+)	1(+)	5(+)	2(+)	8(+)
Senecio serra	4(2)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Senecio streptanthifolius	(0)	(0)	(0)	+(+)	(0)	(0)	1(+)	2(+)	(0)
Senecio triangularis	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Sibbaldia procumbens	(0)	(0)	2(3)	2(+)	1(+)	(0)	(0)	(0)	(0)
Silene menziesii	1(1)	(0)	(0)	1(+)	(0)	(0)	(0)	(0)	(0)
Smilacina racemosa	1(+)	(0)	(0)	1(+)	(0)	(0)	(0)	(0)	(0)
Smilacina stellata	(0)	(0)	(0)	1(1)	(0)	1(1)	(0)	1(+)	(0)
Solidago spathulata	(0)	6(1)	6(5)	3(1)	2(+)	1(+)	4(1)	2(2)	6(1)
Stellaria jamesiana	7(5)	1(2)	1(+)	3(1)	2(+)	1(+)	1(+)	5(1)	(0)
Streptopus amplexifolius	(0)	(0)	(0)	+(+)	(0)	(0)	(0)	(0)	(0)
Thalictrum fendleri	8(3)	1(+)	2(+)	2(1)	1(+)	(0)	1(+)	2(+)	3(+)
Viola adunca	(0)	(0)	3(1)	3(1)	1(+)	(0)	(0)	1(+)	1(+)
Viola nuttallii	3(1)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)
Viola purpurea	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)	(0)

(+) = COVER <0.5%; CODE TO CONSTANCY VALUES: + = 0-5%, 1 = 5-15%, 2 = 15-25%, 3 = 25-35%, 4 = 35-45%, 5 = 45-55%, 6 = 55-65%, 7 = 65-75%, 8 = 75-85%, 9 = 85-95%, 10 = 95-100%

APPENDIX D-1. GENERAL LANDFORM AND SOIL CHARACTERISTICS (upper 20 cm) OF NORTHERN UTAH HABITAT TYPES AND PHASES

	PIFL SERIES		PINUS PONDEROSA SERIES				PSEUDOTSUGA MENZIESII SERIES								
	CELE h.t.	BERE h.t.	CAGE h.t.	FEID h.t.			PHMA h.t.	ACGL h.t.	CELE h.t.	OSCH h.t.	BERE h.t.				CYOR h.t.
				ARPA phase	ARTR phase	FEID phase					CAGE phase	JUCO phase	SYOR phase	BERE phase	
Number of Stands	7	5	8	8	6	15	44	17	10	27	13	11	11	39	7
							COARSE FRAGMENT COMPOSITION (in percent occurrence)								
SEDIMENTARY															
Limestone, dolomite	43	20	--	--	--	--	23	24	57	37	23	27	18	29	29
Sandstone	--	--	--	--	--	7	2	12	--	4	--	--	--	--	--
Tufaceous sandstone 1/	--	--	12	--	--	--	--	--	--	--	--	9	--	--	--
Sandstone-mudstone 2/	--	--	--	38	17	33	5	--	--	--	15	27	--	--	14
Shale	--	--	--	--	--	--	--	--	--	--	--	--	--	3	--
Conglomerate 3/	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Mixed calcareous 4/	14	80	--	--	--	--	51	35	43	26	31	28	46	40	29
METAMORPHIC															
Quartzite	43	--	88	62	83	60	14	29	--	33	31	9	36	22	14
Quartzite-argillite	--	--	--	--	--	--	5	--	--	--	--	--	--	3	14
Schist-quartzite	--	--	--	--	--	--	--	--	--	--	--	--	--	3	--
Schist-gneiss	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
IGNEOUS															
Granitoid rocks	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Andesitic pyroclastics	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Number of observations	7	5	8	8	6	15	43	17	7	27	13	11	11	37	7
							REGOLITH (in percent occurrence)								
RESIDUAL ORDER 5/															
Mineral Class	--	--	100	38	100	93	--	--	--	--	33	36	100	34	71
Freeze-Thaw Class	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
DEPOSITIONAL ORDER															
Colluvium Class	100	--	--	12	--	--	100	100	--	100	67	55	--	58	29
Alluvium Class	--	--	--	--	--	--	--	--	--	--	--	9	--	--	--
Drift Class	--	--	--	50	--	7	--	--	--	--	--	--	--	8	--
Number of observations	1	0	8	8	6	15	2	2	0	1	9	11	1	12	7
							GROUND SURFACE								
SURFACE ROCK EXPOSED (mean %)	13	13	0	20	5	50	3	6	9	0	11	7	11	5	12
BARE SOIL EXPOSED (mean %)	3	1	0	2	0	0	1	1	5	1	2	0	1	1	1
DUFF DEPTH (mean cm)	1.0	1.7	2.9	3.9	2.4	2.6	7.1	5.5	3.4	6.2	4.0	3.1	3.2	5.0	4.1
Number of observations 6/	4/7	5/5	3/8	6/8	4/6	3/15	44/44	17/17	10/10	25/27	11/12	8/11	10/11	33/39	3/7
							UPPER SOIL (in percent occurrence)								
COARSE FRAGMENT PRESENCE															
None significantly noted	--	--	12	--	--	--	10	--	--	33	--	--	--	--	--
Gravelly (3" in shape)	33	100	12	--	17	--	18	56	100	50	11	9	27	36	14
Cobbly (3-8" in shape)	--	--	-	--	17	--	--	11	--	--	11	--	—	9	--
Stony (8" in shape)	33	--	13	--	--	--	62	22	--	17	11	--	46	14	--
Gravelly-cobbly	--	--	--	--	32	--	5	--	--	--	33	27	—	9	43
Gravelly-stony	--	--	--	--	17	7	--	--	--	--	--	9	9	5	14
Cobbly-stony	--	—	13	38	--	--	--	--	--	--	--	--	--	18	--
Gravelly-cobbly-stony	34	--	50	62	17	93	5	11	--	--	34	55	18	9	29
Number of observations	6	4	8	8	6	15	21	9	5	12	9	11	11	22	7
TEXTURAL CLASS															
Sand	--	--	--	--	--	--	--	--	10	--	--	--	--	--	--
Loamy sand & sandy loam	14	40	75	75	67	60	2	24	20	7	15	18	--	16	29
Loam	72	—	12	25	33	40	24	18	20	30	54	46	27	14	29
Silt loam & silt	--	--	--	--	--	--	22	24	10	19	23	--	18	27	--
Silty clay loam & clay loam	14	60	12	--	--	--	52	34	40	44	8	36	55	43	42
Number of observations	7	5	8	8	6	15	42	17	10	27	13	11	11	37	7

(cont.)

1/ Browns Park formation of southern and eastern Uinta Mountains (= Tbp)
2/ Duschense River formation of southern Uinta Mountains (= Tdr)
3/ Wasatch and Knight conglomerates, comprised principally of quartziferous and shaly fragments (= Tw and Tk)
4/ Limestone and dolomite fragments in part, locally with others of sandstone, shale, quartzite, or argillite
5/ Adapted from DeGraff and others 1977
6/ Number of observations for exposed rock-soil and duff depth, respectively

	PIPU SERIES	ABIES CONCOLOR SERIES				PICEA ENGELMANNII SERIES		ABIES LASIOCARPA SERIES							
	AGSP h.t.	BERE h.t.	PHMA h.t.	OSCH h.t.	BERE h.t. SYOR phase	BERE h.t. BERE phase	EQAR h.t.	CALE h.t.	VACA h.t.	VASC h.t.	CACA h.t.	STAM h.t.	ACRU h.t.	PHMA h.t.	ACGL h.t.
Number of Stands	7	9	8	5	8	13	6	5	14	17	5	3	11	10	22
COARSE FRAGMENT COMPOSITION (in percent occurrence)															
SEDIMENTARY															
Limestone, dolomite	86	22	--	--	12	38	--	--	--	--	--	-	27	10	10
Sandstone	--	--	12	--	--	--	--	--	--	--	--	-	--	20	--
Tufaceous sandstone 1/	--	--	--	--	--	--	--	--	14	--	--	--	--	--	--
Sandstone-mudstone 2/	--	--	--	--	--	--	--	40	7	--	--	--	-	-	5
Shale	--	--	--	--	--	--	--	--	--	--	--	--	-	-	5
Conglomerate 3/	--	--	--	--	--	--	17	--	--	--	--	--	-	-	5
Mixed clacareous 4/	14	56	38	20	25	23	--	--	--	--	--	--	36	30	28
METAMORPHIC															
Quartzite	--	22	--	20	38	24	50	60	79	88	100	100	28	-	37
Quartzite-argillite	--	--	38	—	--	15	--	--	--	12	--	--	9	30	--
Schist-quartzite	--	--	--	--	--	--	--	--	--	--	-	-	--	--	--
Schist-gneiss	--	--	--	20	12	--	--	--	--	--	--		--	--	5
IGNEOUS															
Granitoid rocks	--	--	12	40	13	--	17	--	--	--	--	--	--	10	5
Andesitic pyroclastics	--	--	--	--	--	--	16	--	--	--	-	--	-	-	--
Number of observations	7	9	8	5	8	13	6	5	14	17	5	3	11	10	21
REGOLITH (in percent occurrence)															
RESIDUAL ORDER 5/															
Mineral Class	71	34	--	--	17	--	--	60	29	12	--	--	17	--	33
Freeze-Thaw Class	--	--	--	--	--	--	--	--	14	6	--	--	--	--	--
DEPOSITIONAL ORDER															
Colluvium Class	29	44	50	--	50	78	33	-	-	—	40	--	--	20	33
Alluvium Class	--	--	--	33	--	11	33	--	--	--	40	100	--	--	--
Drift Class	--	22	50	67	33	11	34	40	57	82	20	--	83	80	31
Number of observations	7	9	2	3	6	9	6	5	14	17	5	3	6	5	3
GROUND SURFACE															
SURFACE ROCK EXPOSED (mean %)	48	1	4	31	18	8	1	3	10	10	0	7	2	4	2
BARE SOIL EXPOSED (mean %)	2	0	1	1	3	2	0	0	0	0	0	1	2	1	1
DUFF DEPTH (mean cm)	1.0	3.4	5.0	3.9	2.5	3.5	6.4	3.4	3.1	2.6	3.0	7.3	5.1	3.8	5.5
Number of observations 6/	4/7	6/9	6/8	4/5	5/8	8/13	5/6	3/5	9/14	5/17	2/5	3/3	10/11	9/10	20/22
UPPER SOIL (in percent occurrence)															
COARSE FRAGMENT PRESENCE															
None significantly noted	--	22	--	--	--	--	32	--	--	--	60	67	--	--	11
Gravelly (<3" in shape)	57	22	33	33	32	31	17	--	--	6	--	--	100	50	34
Cobbly (3-8" in shape)	--	11	17	33	17	--	--	20	21	--	--	--	--		11
Stony (>8" in shape)	--	--	17	--	17	8	--	20	--	12	--	--	--	--	22
Gravelly-cobbly	29	34	--	34	17	30	--	--	--	6	20	--	--	--	--
Gravelly-stony	14	11	--	--	--	8	17	--	--	--	--	--	--	--	-
Cobbly-stony	--	--	--	--	--	--	17	--	29	24	--	-	--	-	
Gravelly-cobbly-stony	--	--	33	--	17	23	17	60	50	52	20	33	-	50	22
Number of observations	7	9	6	3	6	13	6	5	14	17	5	3	6	4	9
TEXTURAL CLASS															
Sand	--	--	--	--	--	--	--	--	--	6	--	--	--	--	4
Loamy sand & sandy loam	--	22	--	40	38	23	17	--	14	53	20	33	--	--	18
Loam	71	11	75	40	25	31	33	60	36	35	40	--	27	40	14
Silt loam & silt	--	11	12	--	12	--	--	--	--	--	--	--	9	--	14
Silty clay loam & clay loam	29	56	13	20	25	46	50	40	50	6	40	67	64	60	50
Number of observations	7	9	8	5	8	13	6	5	14	17	5	3	11	10	22

(cont.)

1/ Browns Park formation of southern and eastern Uinta Mountains (= Tbp)
2/ Duschense River formation of southern Uinta Mountains (= Tdr)
3/ Wasatch and Knight conglomerates, comprised principally of quartziferous and shaly fragments (= Tw and Tk)
4/ Limestone and dolomite fragments in part, locally with others of sandstone, shale, quartzite, or argillite
5/ Adapted from DeGraff and others 1977
6/ Number of observations for exposed rock-soil and duff depth, respectively

	ABIES LASIOCARPA SERIES (cont.)													
	VACA h.t.	VAGL h.t.	VASC h.t.			CARU h.t.	PERA	PERA	BERE h.t.					
			ARLA phase	CAGE phase	VASC phase		PSME phase	PERA phase	PIFL phase	RIMO phase	CAGE phase	JUCO phase	PSME phase	BERE phase
Number of Stands	12	28	28	9	47	17	32	34	19	58	17	15	73	32
COARSE FRAGMENT COMPOSITION (in percent occurrence)														
SEDIMENTARY														
Limestone, dolomite	--	--	--	--	--	--	6	3	18	23	6	7	23	--
Sandstone	8	4	--	--	2	--	--	3	--	5	12	7	7	--
Tufaceous sandstone 1/	17	--	--	--	2	6	--	--	--	--	6	13	--	--
Sandstone-mudstone 2/	8	--	--	--	9	--	--	--	--	--	--	--	1	3
Shale	--	--	--	--	--	6	--	--	--	--	--	--	--	--
Conglomerate 3/	--	21	7	--	2	29	16	58	24	9	--	--	9	31
Mixed clacareous 4/	--	4	--	--	2	--	16	3	12	18	29	13	42	19
METAMORPHIC														
Quartzite	50	67	82	100	81	53	52	24	40	24	41	60	13	32
Quartzite-argillite	--	--	7	--	2	--	4	3	6	2	6	--	--	3
Schist-quartzite	--	--	--	--	--	6	--	--	--	5	--	--	1	3
Schist-gneiss	--	--	--	--	--	--	--	--	--	--	--	--	3	3
IGNEOUS														
Granitoid rocks	--	--	--	--	--	--	--	--	--	7	--	--	1	3
Andesitic pyroclastics	17	4	4	--	--	--	6	6	--	7	--	--	--	3
Number of observations	12	24	28	9	47	17	31	33	17	57	17	15	68	32
REGOLITH (in percent occurrence)														
RESIDUAL ORDER 5/														
Mineral Class	60	--	27	--	67	67	14	80	66	65	66	54	34	33
Freeze-Thaw Class	--	--	--	--	--	--	--	--	--	--	--	--	--	--
DEPOSITIONAL ORDER														
Colluvium Class	10	40	5	17	9	33	29	20	17	23	17	8	22	7
Alluvium Class	--	--	--	--	--	--	--	--	--	--	--	8	--	--
Drift Class	30	60	68	83	24	--	57	--	17	12	17	30	44	60
Number of observations	10	5	22	6	45	6	7	5	6	26	12	13	18	15
GROUND SURFACE														
SURFACE ROCK EXPOSED (mean %)	12	6	10	17	15	1	2	2	10	9	6	8	3	4
BARE SOIL EXPOSED (mean %)	1	1	1	2	2	0	0	2	3	1	1	2	1	1
DUFF DEPTH (mean cm)	3.2	4.6	3.2	1.9	2.6	3.1	4.3	6.2	4.4	3.7	3.2	3.2	3.2	3.2
Number of observations 6/	9/12	26/28	24/27	8/9	29/47	7/17	26/31	25/34	12/17	48/58	12/16	9/15	52/72	16/32
UPPER SOIL (in percent occurrence)														
COARSE FRAGMENT PRESENCE														
None significantly noted	--	--	--	--	--	9	--	7	--	8	13	--	17	6
Gravelly (<3" in shape)	42	40	25	67	26	46	70	60	13	50	34	36	28	56
Cobbly (3-8" in shape)	--	7	4	--	2	9	--	--	--	3	13	7	9	6
Stony (>8" in shape)	--	33	4	--	7	9	15	13	40	8	7	7	26	--
Gravelly-cobbly	16	--	30	22	4	--	--	20	13	16	13	14	6	12
Gravelly-stony	--	--	4	--	--	9	--	--	--	3	13	--	3	--
Cobbly-stony	--	7	8	--	2	--	--	--	--	--	--	--	--	--
Gravelly-cobbly-stony	42	13	25	11	59	18	15	--	34	12	7	36	11	20
Number of observations	12	15	24	9	46	11	13	15	15	38	15	14	35	16
TEXTURAL CLASS														
Sand	8	4	7	22	4	--	--	--	--	2	--	--	1	3
Loamy sand & sandy loam	25	--	21	33	45	18	6	15	22	14	18	46	11	28
Loam	33	14	43	11	21	41	25	30	22	40	35	40	29	44
Silt loam & silt	17	18	4	34	19	--	--	9	12	4	12	7	1	6
Silty clay loam & clay loam	17	64	25	--	11	41	69	46	44	40	35	7	58	19
Number of observations	12	28	28	9	47	17	32	33	18	58	17	15	70	32

(cont.)

1/ Browns Park formation of southern and eastern Uinta Mountains (= Tbp)
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3/ Wasatch and Knight conglomerates, comprised principally of quartziferous and shaly fragments (= Tw and Tk)
4/ Limestone and dolomite fragments in part, locally with others of sandstone, shale, quartzite, or argillite
5/ Adapted from DeGraff and others 1977
6/ Number of observations for exposed rock-soil and duff depth, respectively

APPENDIX D-1 (con.)

	ABIES LASIOCARPA SERIES (cont.)						PINUS CONTORTA SERIES						
	RIMO h.t.				OSCH h.t.	JUCO h.t.	CACA c.t.	VACA c.t.	VASC c.t.	JUCO c.t.	ARUV h.t.	BERE c.t.	CARO h.t.
	TRSP phase	PICO phase	THFE phase	RIMO phase									
Number of Stands	18	8	29	22	12	12	9	29	18	14	24	20	8
					COARSE FRAGMENT COMPOSITION (in percent occurrence)								
SEDIMENTARY													
Limestone, dolomite	--	--	11	21	17	--	--	--	--	--	--	--	--
Sandstone	--	--	14	--	--	--	--	--	--	7	--	5	--
Tufaceous sandstone 1/	--	--	--	--	--	--	22	21	22	--	--	35	--
Sandstone-mudstone 2/	11	100	--	--	--	75	--	--	--	43	--	--	--
Shale	--	--	--	--	--	--	--	--	--	--	--	--	--
Conglomerate 3/	--	--	11	26	50	--	--	--	--	--	--	--	--
Mixed clacareous 4/	--	--	18	22	25	--	--	--	6	--	--	--	--
METAMORPHIC													
Quartzite	89	--	20	26	--	25	78	79	72	29	96	60	100
Quartzite-argillite	--	--	4	--	--	--	--	--	--	21	4	--	--
Schist-quartzite	--	--	--	--	--	--	--	--	--	--	--	--	--
Schist-gneiss	--	--	7	--	8	--	--	--	--	--	--	--	--
IGNEOUS													
Granitoid rocks	--	--	4	5	--	--	--	--	--	--	--	--	--
Andesitic pyroclastics	--	--	11	--	--	--	--	--	--	--	--	--	--
Number of observations	18	8	28	19	12	12	9	29	18	14	24	20	8
					REGOLITH (in percent occurrence)								
RESIDUAL ORDER 5/													
Mineral Class	50	100	44	50	--	84	56	41	41	50	50	75	75
Freeze-Thaw Class	28	--	--	--	--	--	--	--	--	--	--	--	--
DEPOSITIONAL ORDER													
Colluvium Class	--	--	6	--	--	8	11	--	6	29	--	5	--
Alluvium Class	--	--	--	--	--	--	11	--	--	7	--	--	--
Drift Class	22	--	50	50	100	8	22	59	53	14	50	20	25
Number of observations	18	8	18	4	2	12	9	29	17	14	24	20	8
					GROUND SURFACE								
SURFACE ROCK EXPOSED (mean %)	43	0	2	2	0	16	1	5	12	29	9	5	3
BARE SOIL EXPOSED (mean %)	15	0	0	0	2	3	0	0	0	1	1	0	1
DUFF DEPTH (mean cm)	1.2	1.4	3.6	3.9	2.3	2.9	3.0	3.0	2.9	2.7	2.7	3.2	2.5
Number of observations 6/	6/18	0/8	22/28	17/22	8/12	4/12	6/9	24/29	14/17	7/14	16/24	13/20	8/8
					UPPER SOIL (in percent occurrence)								
COARSE FRAGMENT PRESENCE													
None significantly noted	--	--	14	8	--	--	38	7	--	7	--	--	--
Gravelly (<3" in shape)	6	12	62	38	80	8	25	7	19	--	22	10	25
Cobbly (3-8" in shape)	--	--	--	23	--	--	12	4	6	--	--	30	--
Stony (>8" in shape)	--	--	--	--	20	--	12	11	6	--	4	5	--
Gravelly-cobbly	--	--	5	23	--	--	--	34	19	7	9	25	--
Gravelly-stony	--	--	--	--	--	--	--	--	6	--	22	--	50
Cobbly-stony	--	--	--	--	--	--	--	11	12	--	--	10	12
Gravelly-cobbly-stony	94	88	19	8	--	92	13	26	32	86	43	20	13
Number of observations	18	8	21	13	5	12	8	27	16	14	23	20	8
TEXTURAL CLASS													
Sand	6	--	4	--	--	8	--	--	11	--	8	--	--
Loamy sand & sandy loam	56	62	14	9	17	92	11	52	56	93	71	70	62
Loam	32	38	39	22	33	--	56	31	16	--	17	25	38
Silt loam & silt	--	--	18	5	8	--	--	3	6	--	--	--	--
Silty clay loam & clay loam	6	--	25	64	42	--	33	14	11	7	4	5	--
Number of observations	18	8	28	22	12	12	9	29	18	14	24	20	8

1/ Browns Park formation of southern and eastern Uinta Mountains (= Tbp)
2/ Duschense River formation of southern Uinta Mountains (= Tdr)
3/ Wasatch and Knight conglomerates, comprised principally of quartziferous and shaly fragments (= Tw and Tk)
4/ Limestone and dolomite fragments in part, locally with others of sandstone, shale, quartzite, or argillite
5/ Adapted from DeGraff and others 1977
6/ Number of observations for exposed rock-soil and duff depth, respectively

APPENDIX D-2 CLIMATIC PARAMETERS FOR STATIONS WITHIN OR PROXIMATE TO HABITAT TYPES OF SERIES IN NORTHERN UTAH (FROM U.S. WEATHER SERVICE RECORDS UNLESS NOTED) (~ = APPROXIMATELY; ND = NO DATA)

Geographic location and station	Estimated habitat types and phase or position to nearest adjacent climax series	Mean monthly temperature July	Mean monthly temperature Jan.	Average number of frosts (32°F-0°C) June-August	Mean annual precipitation	Mean May-Aug. precipitation	Mean annual snowfall	Longitude/ latitude	Elevation	Record period
		°F(°C)	*°F(°C)*		*Inches (mm)*	*Inches (mm)*	*Inches (mm)*		*Feet (meters)*	
NORTHERN WASATCH										
Utah State University	below PSME series	73(23)	40(4)	0	18.3 (465)	4.2 (107)	74 (1 880)	111°49'/41°44'	4,780 (1 457)	1971-76
College Forest[1]	ABLA/PERA-PERA	58(15)	14(–10)	ND	40.1 (1 019)	5.3 (135)	ND	111°30'/41°52'	8,500 (2 591)	1971-76
CENTRAL WASATCH										
Cottonwood Weir	below ABCO series	80(27)	33(~1)	0	21.7 (551)	5.4 (137)	86 (2 184)	111°47'/40°27'	4,961 (1 512)	1951-60
Timpanogos Cave	ABCO/BERE-BERE[2]	73(23)	29(–2)	/ 0	22.1 (561)	5.8 (147)	112 (2 845)	111°43'/40°27'	5,523 (1 683)	1951-60
Silver Lake Brighton	ABLA/BERE-RIMO	58(15)	19(–8)	10	41.7 (1 059)	8.4 (213)	410 (10 414)	111°35'/40°36'	8,700 (2 652)	1951-60
NORTHEASTERN UINTAS										
Flaming Gorge	below PIPO series[3]	68(20)	21(–6)	1	12.4 (315)	5.0 (127)	46 (1 168)	109°25'/40°56'	6,270 (1 911)	1957-75
SOUTH-CENTRAL UINTAS										
Elkhorn R.S.	below POTR series[4]	ND	ND	ND	12.0 (305)	4.1 (104)	69 (1 753)	109°57'/40°33'	6 850 (2 088(	1951-56
Moon Lake	PSME/BERE-JUCO	60(16)	17(–8)	11	19.0 (483)	7.0 (178)	ND	110°30'/40°34'	8,150 (2 484)	1951-60

[1]Data from Lomas 1977.
[2]Station is situated above canyon bottom in *Quercus gambelii-Acer grandidentatum* woodland with scattered *Abies concolor* stems; exposure is southerly lower slope and is directly across-canyon from ABCO/BERE h.t., BERE phase, occupying steep northerly slope.
[3]Station is situated in *Pinus edulis-Juniperus osteosperma* woodland.
[4]Station is situated near lower treeline comprised solely of *Populus tremuloides*.

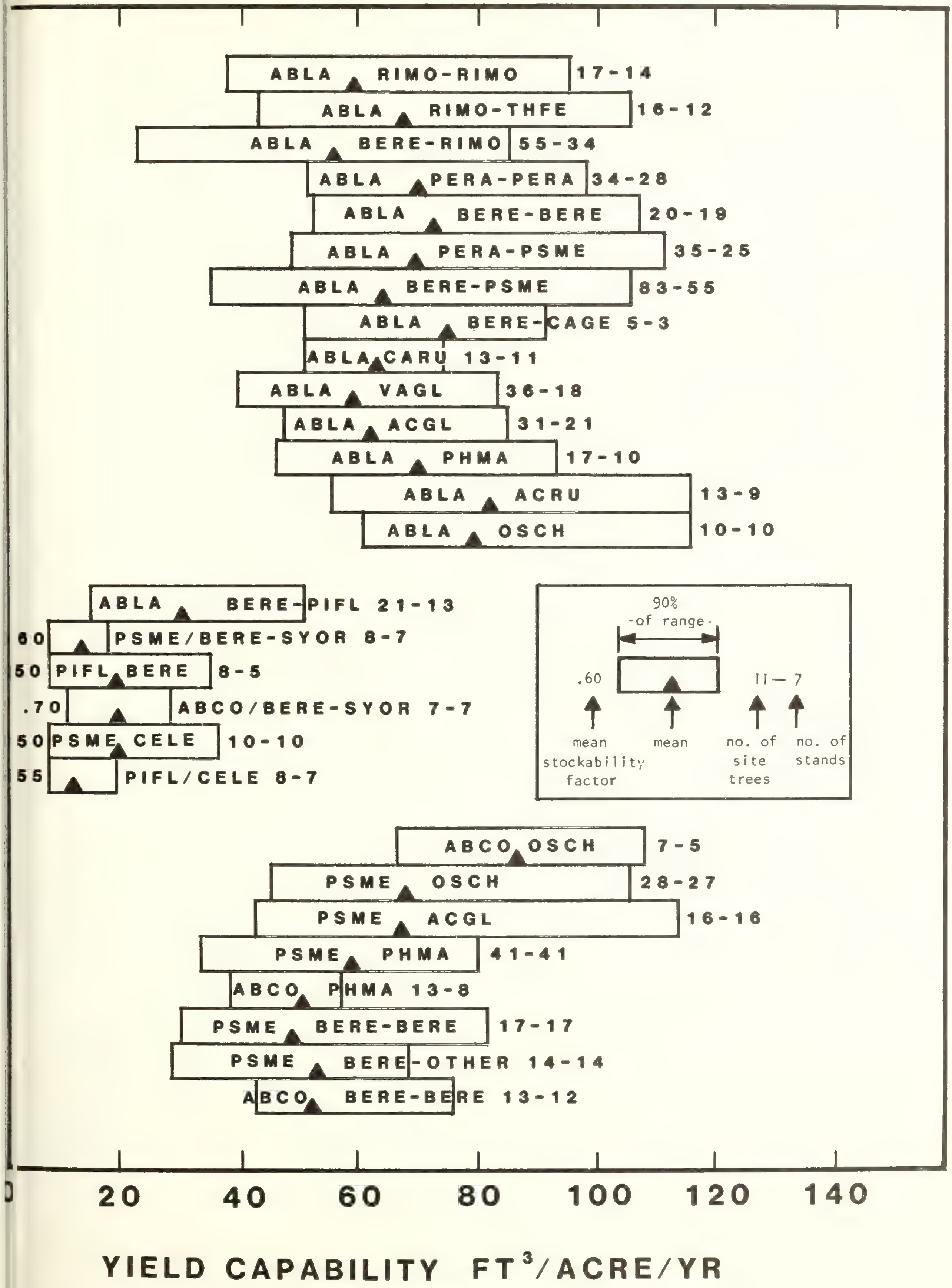
APPENDIX E-1. MEAN BASAL AREAS AND 50-YEAR SITE INDEXES (IN FEET) FOR NORTHWESTERN UTAH SAMPLE STAND DATA BY HABITAT TYPE

Habitat type	Basal area (ft^2/acre)	Site index by species					
		PIFL	PSME	ABCO	PICO	PIEN	ABLA
PIFL/CELE	83 ± 56	16 ± ?	21 ± 4	.	.	.	.
PIFL/BERE	78 ± 43	31 ± ?	39 ± ?	.	.	.	.
PSME/CELE	90 ± 69	.	27 ± 6	.	.	.	.
PSME/PHMA	140 ± 19	.	49 ± 3	.	.	.	.
PSME/ACGL	174 ± 47	.	53 ± 6	.	.	.	.
PSME/OSCH, PRVI	149 ± 23	.	52 ± 4	.	.	.	.
PSME/OSCH, OSCH	182 ± 41	.	54 ± 6	.	.	.	.
PSME/BERE, BERE	176 ± 37	.	42 ± 5	.	.	.	.
PSME/BERE, SYOR	199 ± 85	.	26 ± 6	.	.	.	.
PSME/BERE, other	134 ± 31	.	46 ± 5	.	.	.	.
ABCO/PHMA	194 ± 37	.	44 ± 5	44 ± 5	.	.	.
ABCO/OSCH	244 ± 56	.	63 ± ?	62 ± ?	.	.	.
ABCO/BERE, SYOR	126 ± 54	.	.	27 ± 3	.	.	.
ABCO/BERE, BERE	186 ± 35	.	46 ± 5	38 ± ?	.	.	.
ABLA/ACRU	203 ± 55	.	63 ± ?	.	.	61 ± ?	55 ± 12
ABLA/PHMA	152 ± 35	.	50 ± 7	.	.	58 ± ?	56 ± 16
ABLA/ACGL	189 ± 40	.	51 ± 4	.	.	.	47 ± 5
ABLA/VAGL	208 ± 35	.	46 ± 8	.	46 ± 3	49 ± 5	45 ± 8
ABLA/CARU	193 ± 40	.	49 ± ?	.	51 ± 3	.	.
ABLA/PERA, PSME	234 ± 37	.	54 ± 6	.	45 ± 4	54 ± 4	56 ± 7
ABLA/PERA, PERA	207 ± 20	.	.	.	51 ± 3	56 ± 6	51 ± 6
ABLA/BERE, PIFL	195 ± 63	21 ± 6	36 ± 4	.	.	36 ± ?	31 ± 9
ABLA/BERE, RIMO	228 ± 34	.	46 ± 6	.	47 ± ?	46 ± 5	43 ± 6
ABLA/BERE, CAGE	208 ± ?	.	56 ± ?	.	.	.	.
ABLA/BERE, PSME	196 ± 18	.	48 ± 3	.	48 ± 4	58 ± 8	51 ± 4
ABLA/BERE, BERE	197 ± 45	.	.	.	50 ± 5	61 ± 9	54 ± 12
ABLA/RIMO, THFE	196 ± 52	.	.	.	.	58 ± 19	49 ± 12
ABLA/RIMO, RIMO	206 ± 47	.	43 ± ?	.	.	49 ± 8	47 ± 11
ABLA/OSCH	183 ± 35	.	.	.	.	.	54 ± 9

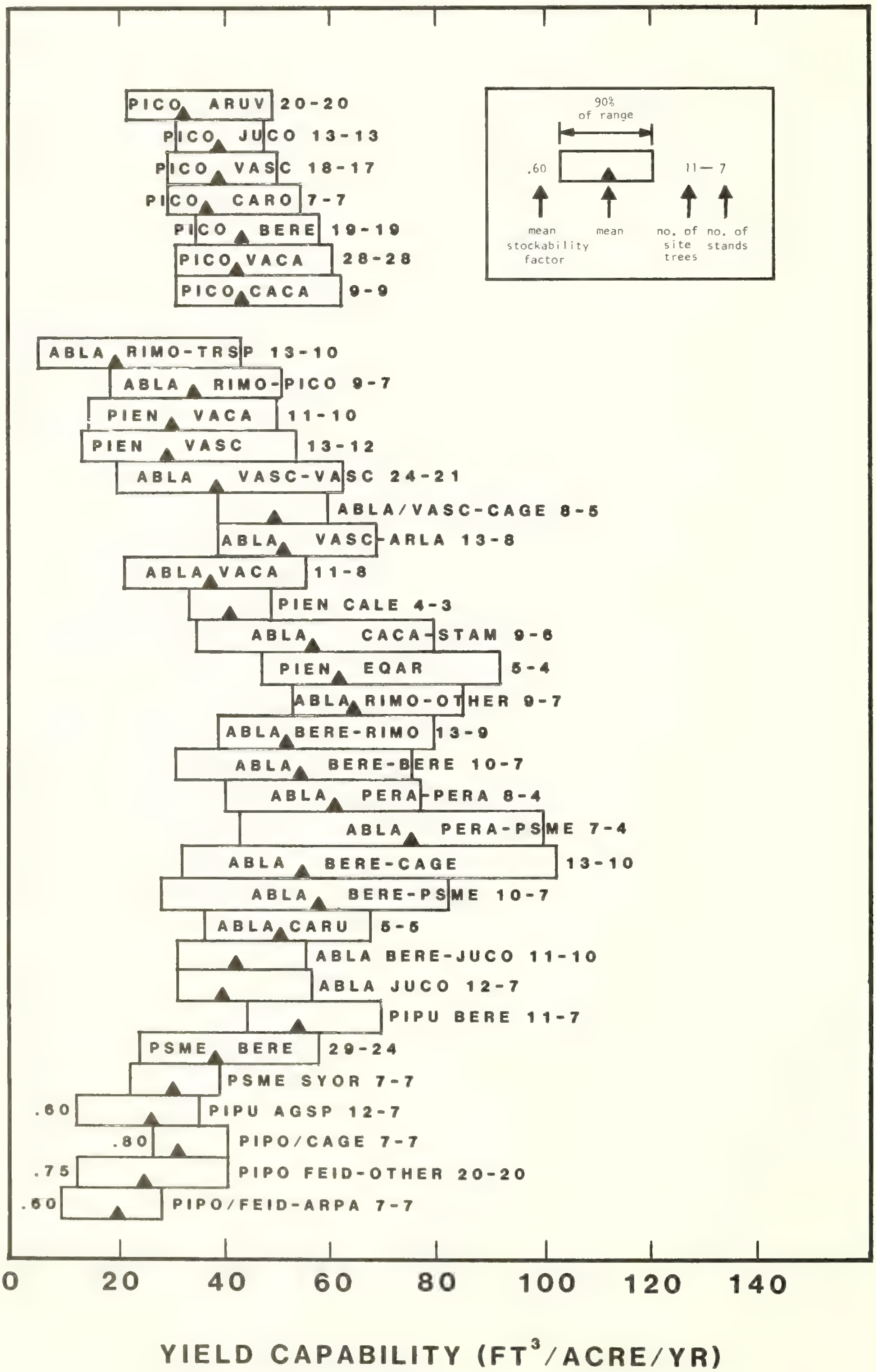
APPENDIX E-2. MEAN BASAL AREAS AND 50-YEAR SITE INDEXES (IN FEET) FOR UINTA MOUNTAINS SAMPLE STAND DATA BY HABITAT TYPE

Habitat type	Basal area (ft^2/acre)	Site index by species					
		PIPO	PSME	PIPU	PICO	PIEN	ABLA
PIPO/CAGE	140 ± 37	39 ± 5	.	.	.	.	.
PIPO/FEID, ARPA	100 ± 30	31 ± 4	.	.	.	.	.
PIPO/FEID, other	117 ± 20	34 ± 3	.	.	.	.	.
PSME/BERE	156 ± 22	44 ± ?	34 ± 4	.	41 ± ?	.	.
PSME/SYOR	160 ± 37	.	30 ± 4	.	.	.	.
PIPU/AGSP	97 ± 32	.	36 ± 3	40 ± 5	.	.	.
PIPU/BERE	166 ± 36	.	.	46 ± 3	43 ± ?	.	.
PIEN/EQAR	202 ± 109	.	.	.	41 ± ?	52 ± ?	.
PIEN/CALE	173 ± ?	.	.	.	32 ± ?	38 ± ?	.
PIEN/VACA	162 ± 38	.	.	.	36 ± 4	25 ± 9	.
PIEN/VASC	178 ± 39	.	.	.	32 ± 6	25 ± 10	.
ABLA/CACA + STAM	227 ± 69	.	.	.	44 ± ?	45 ± ?	.
ABLA/VACA	170 ± 34	.	.	.	34 ± 4	34 ± ?	.
ABLA/VASC, ARLA	182 ± 30	.	.	.	40 ± ?	40 ± 6	45 ± ?
ABLA/VASC, CAGE	141 ± 41	.	.	.	43 ± 7	.	.
ABLA/VASC, VASC	159 ± 16	.	.	.	35 ± 4	35 ± 14	33 ± ?
ABLA/CARU	157 ± 63	.	.	.	43 ± 9	.	.
ABLA/PERA, PSME	170 ± ?	.	46 ± ?	.	.	64 ± ?	.
ABLA/PERA, PERA	201 ± ?	.	.	.	43 ± ?	48 ± ?	.
ABLA/BERE, RIMO	170 ± 51	.	.	.	.	41 ± 10	43 ± 7
ABLA/BERE, CAGE	173 ± 24	.	.	.	40 ± 7	.	61 ± ?
ABLA/BERE, JUCO	160 ± 33	.	.	.	37 ± 5	.	.
ABLA/BERE, PSME	166 ± 27	.	.	.	44 ± ?	.	48 ± ?
ABLA/BERE, BERE	159 ± 47	.	.	.	39 ± 10	.	53 ± ?
ABLA/JUCO	136 ± 44	.	.	.	37 ± 6	.	34 ± ?
ABLA/RIMO, TRSP	111 ± 41	.	.	.	.	25 ± 9	22 ± ?
/RIMO, PICO	158 ± 31	.	.	.	41 ± ?	31 ± 8	.
/RIMO, other	213 ± 39	.	.	.	.	49 ± 7	.
PIPC/CACA	144 ± 35	.	.	.	37 ± 7	.	.
PIPO/VACA	177 ± 21	.	.	.	36 ± 3	.	.
PICO/VASC	183 ± 28	.	.	.	34 ± 3	.	.
PICO/JUCO	158 ± 27	.	.	.	35 ± 3	.	.
PICO/ARUV	146 ± 18	.	.	.	30 ± 3	.	.
PICO/BERE	167 ± 29	.	.	.	37 ± 3	.	.
PICO/CARO	193 ± 43	.	.	.	33 ± 6	.	.

APPENDIX E-3. ESTIMATED YIELD CAPABILITIES OF UINTA MOUNTAINS HABITAT TYPES BASED ON SITE INDEX AND STOCKABILITY FACTORS (CUBIC FEET/ACRE/YEAR)



APPENDIX E-4. ESTIMATED YIELD CAPABILITIES OF UINTAH MOUNTAINS HABITAT TYPES BASED ON SITE INDEX AND STOCKABILITY FACTORS (CUBIC FEET/ACRE/YEAR)



APPENDIX F. NORTHERN UTAH HABITAT TYPE FIELD FORM

NAME

DATE

INSTRUCTIONS: Estimate each species coverage to the nearest 1% when <10% or to the nearest 5% when >10%. Use trace (T) when <.5%. Estimate trees (>4 inches d.b.h.) and regen. (0-4 inches d.b.h.) separately, (e.g. 35/10). Landform and parent material notes are also useful.

POSITION CODES		CONFIGURATION CODES	
1-Ridge	4-Lower slope	1-Convex (dry)	3-Concave (wet)
2-Upper slope	5-Bench/flat	2-Straight	4-Undulate
3-Midslope	6-Stream bottom		

Plot No.				
Meridian				
T				
R				
S				
Elevation				
Aspect				
% Slope				
Topography				
Config.				

TREES	Scientific name	Abbrev.	Common name	CANOPY COVERAGE (%)			
1.	Abies concolor	ABCO	white fir	/	/	/	
2.	Abies lasiocarpa	ABLA	subalpine fir	/	/	/	
3.	Picea engelmannii	PIEN	Engelmann spruce	/	/	/	
4.	Picea pungens	PIPU	Blue spruce	/	/	/	
5.	Pinus contorta	PICO	lodgepole pine	/	/	/	
6.	Pinus flexilis	PIFL	limber pine	/	/	/	
7.	Pinus ponderosa	PIPO	ponderosa pine	/	/	/	
8.	Pseudotsuga menziesii	PSME	Douglas-fir	/	/	/	
9.	Populus tremuloides	POTR	quaking aspen	/	/	/	
10.	Quercus gambelii	QUGA	Gambel oak	/	/	/	
SHRUBS AND SUBSHRUBS							
1.	Acer glabrum	ACGL	mountain maple				
2.	Arctostaphylos patula	ARPA	greenleaf manzanita				
3.	Arctostaphylos uva-ursi	ARUV	bearberry				
4.	Artemisia tridentata	ARTR	big sagebrush				
5.	Berberis repens	BERE	Oregongrape				
6.	Cercocarpus ledifolius	CELE	Curlleaf mountain-mahogany				
7.	Juniperus communis	JUCO	common juniper				
8.	Pachistima myrsinites	PAMY	myrtle pachistima				
9.	Physocarpus malvaceus	PHMA	ninebark				
10.	Prunus virginiana	PRVI	chokecherry				
11.	Ribes monteginum	RIMO	mountain gooseberry				
12.	Sorbus scopulina	SOSC	mountain-ash				
13.	Symphoricarpos oreophilus	SYOR	mountain snowberry				
14.	Vaccinium caespitosum	VACA	dwarf blueberry				
15.	Vaccinium globulare	VAGL	blue huckleberry				
16.	Vaccinium membranaceum	VAME	big whortleberry				
17.	Vaccinium scoparium	VASC	grouse whortleberry				
GRAMINOIDS							
1.	Agropyron spicatum	AGSP	bluebunch wheatgrass				
2.	Calamagrostis canadensis	CACA	bluejoint reedgrass				
3.	Calamagrostis rubescens	CARU	pinegrass				
4.	Carex geyeri	CAGE	elk sedge				
5.	Carex rossii	CARD	Ross sedge				
6.	Festuca idahoensis (+ ovina)	FEID	Idaho fescue				
7.	Leucopoa kingii	LEKI	spike-fescue				
8.	Trisetum spicatum	TRSP	spike trisetum				
FORBS AND FERN ALLIES							
1.	Actaea rubra	ACRU	baneberry				
2.	Arnica cordifolia	ARCO	heartleaf arnica				
3.	Arnica latifolia	ARLA	broadleaf arnica				
4.	Caltha leptosepala	CALE	elkslip marshmarigold				
5.	Equisetum arvense	EQAR	common horsetail				
6.	Osmorhiza chilensis (+ depauperata)	OSCH	mountain sweetroot				
7.	Pedicularis racemosa	PERA	sickletop pedicularis				
8.	Senecio triangularis	SETR	arrowleaf groundsel				
9.	Streptopus amplexifolius	STAM	claspleaf twisted-stalk				
10.	Thalictrum fendleri	THFE	Fendler meadowrue				

SERIES ______

HABITAT TYPE ______

PHASE ______

☆U.S. GOVERNMENT PRINTING OFFICE: 1984-0-776-032/10,503

Mauk, Ronald L.; Henderson, Jan A. Coniferous forest habitat types of northern Utah. General Technical Report INT-170. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 89 p.

A land classification system based upon potential natural vegetation is presented for the coniferous forests of northern Utah. The classification and descriptions are based on reconnaissance data from over 1,000 stands. A total of 8 climax series and 36 habitat types are described. A diagnostic key, utilizing conspicuous indicator species, provides for field identification of the types.

KEYWORDS: forest vegetation, Utah, habitat types, plant communities, forest ecology, forest management, classification

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

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Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station
Ogden, Utah 84401**

General Technical
Report INT-171

August 1984

Wilderness Fire Management Planning Guide

William C. Fischer

THE AUTHOR

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Those listed below not only reviewed previous drafts of this report, they also offered suggestions based on experience as resource managers dealing with fire and wilderness management. Many of them authored and implemented the first National Park and National Forest wilderness fire management plans in North America. Others are currently involved in developing new plans or administering existing ones. The content of this guide has been strongly influenced by the comments, suggestions, and accomplishments of these people.

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RESEARCH SUMMARY

Current fire management policies of Federal land management agencies generally recognize fire as a natural process in many forest and range ecosystems, especially in the West. Consequently, fire is allowed or encouraged to more nearly play its natural role in wildernesses, parks, refuges, and other areas managed in whole or in part to maintain primitive or presettlement conditions. The tasks associated with such policies are collectively known as wilderness fire management.

In this report, wilderness fire management is defined as the deliberate response to and use of fire through the execution of technically sound plans under specific prescriptions for the purpose of achieving stated wilderness management objectives. Four types of manager response to fire are identified: aggressive attack, delayed attack, modified attack, and allowing a fire to burn according to a predetermined prescription. Wilderness fire management planning is the process of determining the appropriate response to accidental fire and the use of manager-initiated fire to accomplish wilderness management objectives.

This report attempts to guide wilderness fire management planning by suggesting a common terminology, examining important planning concepts, and identifying, describing, and discussing essential planning elements.

Among the planning concepts examined are the appropriate planning area, the planning context, and the format and content of the wilderness fire management plan. Special attention is given to the relationship of the wilderness fire management plan to the various other plans that exist in the planning hierarchy of most agencies. The relationship between National Environmental Policy Act (NEPA) requirements and wilderness fire management planning is illustrated using the Forest Service NEPA process as an example.

Wilderness fire management planning is separated nto six essential elements in this report:

1. Describing fire and ecosystem interactions
2. Describing special resource and use considerations
3. Defining fire management objectives
4. Delineating fire management units and zones
5. Developing fire management prescriptions
6. Devising a fire management plan

Each of these planning elements is defined and liscussed in terms of planning approach, information ıeeds, and methods of presentation. Appropriate exımples for actual wilderness fire management plans ıre presented to illustrate methods.

A summary of current wilderness fire management ›rograms in the National Parks and National Forests s presented as an appendix. A second appendix proides a bibliographic listing of selected references for ark and wilderness fire management. References are rouped according to seven subject areas: philosophy, rograms, and plans; planning aids and general information sources; fire history; fire occurrence, fire environment, and fire behavior; the role of fire and fire ffects; vegetation inventory, classification, and nalysis; and ecosystem classification.

CONTENTS

Wilderness Fire Management Planning Guide

William C. Fischer

NTRODUCTION

The purpose of this report is to guide and aid fire ıanagement planning for parks, wildernesses, and other rild, natural, or essentially undeveloped areas. A hilosophy and general approach to wilderness fire ıanagement planning is emphasized. The intent is not o propose a rigid format or to specify particular ıethods. Wilderness fire management plans, like the reas they represent, will vary in content, complexity, nd scope. Nevertheless, wilderness fire management lans should share a common purpose and uniform planing procedure.

The suggested approach to wilderness fire manageıent planning is essentially a two-step process. The first tep involves developing specific fire management objecives based on agency policy, management direction, the hysical and biological characteristics of the planning rea, the probable ecological effects of fires and the bsence of fire, and the likely effects of different fire uppression actions on the environment. The second step s to translate the specific fire management objectives ıto planned actions for responding to fire or for the use f fire on specific lands within the planning area.

It is important to note that this is a planning guide. t is not a policy implementation guide. Its utility, herefore, is not limited to a particular agency. In other rords, this guide was written with the hope that all fire ıanagement agencies would find it equally useful as a ommon reference for fire management planning.

Wilderness fire management is a relatively new activiy. A universally accepted terminology is, consequently, acking. Different terms are often used to identify idenical processes. Conversely, identical terms are often sed to identify different processes. Definitions are often nrelated to the literal meaning of the terminology. The erms used in this guide are based on standard dicionary definitions. The goal is to provide a terminology hat is both logical and easy to understand.

The terminology promulgated here will differ from curent terminologies of various land management agencies. Ianagers and planners are cautioned, therefore, to eview agency policy regarding fire management terıinology before using the suggested terms in plans or ther official documents.

EVOLUTION OF WILDERNESS FIRE MANAGEMENT POLICY

Wilderness Policy

The Wilderness Act[1] requires that lands designated as components of the National Wilderness Preservation System "be administered . . . in such manner as will leave them unimpaired for future use and enjoyment as wilderness, and so as to provide for the protection of these areas, the preservation of their wilderness character, and for the gathering and dissemination of information regarding their use and enjoyment as wilderness." The act defines wilderness ". . . as an area where the earth and its community of life are untrammeled by man, where man himself is a visitor who does not remain." An area of wilderness is further defined to mean in the act an area of undeveloped Federal land retaining its primeval character and influence, without permanent improvements or human habitation, which is protected and managed so as to preserve its natural conditions and which (1) generally appears to have been affected primarily by the forces of nature, with the imprint of man's work substantially unnoticeable; (2) has outstanding opportunities for solitude or a primitive and unconfined type of recreation; (3) has at least 5,000 acres (2 023 ha) of land or is of sufficient size as to make practicable its preservation and use in an unimpaired condition; and (4) may also contain ecological, geological, or other features of scientific, educational, scenic, or historical value.

Fire is a natural force that has helped shape the character of much of the American wilderness. According to Heinselman (1978), full recognition of fire's role "is only now pervading ecological theory, but it seems clear that many of the forest, grassland, and savanna ecosystems of the primeval American wilderness were fire dependent." An ecosystem can be called fire dependent if periodic perturbations by fire are essential to the functioning of the system (Heinselman 1978). In such ecosystems "fire initiated and terminated vegetational

[1]An Act to establish a National Wilderness Preservation System for the permanent good of the whole people, and for other purposes. Public Law 88-557, 88th Congress, S.4, September 3, 1964.

succession; controlled the age structure and species composition of the vegetation; produced the mosaic of vegetation types of the landscape; affected insect and plant pathogen populations; influenced nutrient cycles and energy flows; regulated the biotic productivity, diversity, and stability of the system; and determined the habitats available to wildlife" (Heinselman 1978).

Fire Management

Federal land management agencies generally pursued a policy of total fire control at the time the Wilderness Act was enacted. Discovered fires were aggressively attacked and eventually contained and controlled under such a policy. The fire control policy was applied to all lands regardless of classification or primary use. The use of certain fire suppression equipment was, however, often regulated by agency policy in wilderness areas.

The apparent conflict between overall wilderness management direction and fire control objectives was recognized by land managers even though fire control was specifically authorized in the Wilderness Act. There occurred, in fact, a general recognition that fire control activities should, in large part, be dictated by land management objectives on all Federal lands. The policy of fire control gradually changed, therefore, to a policy of fire management (Moore 1974; DeBruin 1976; Kilgore 1976a; Turcott 1979). Several definitions of the term "fire management" have been proposed (Barney 1975; Simard 1976) and other definitions implied (Barrows 1974; Mutch 1977; Heinselman 1978). It is difficult to present a single authoritative definition of fire management because the term is routinely used in two different contexts: a land management philosophy and a land management activity. As a management philosophy, fire management suggests that fire, in an ecological sense as well as in a protective sense, should be considered when developing land and resource management objectives, and that fire-related activities should be designed to accomplish these objectives. As a land management activity, fire management includes all the tasks related to the inclusion of fire considerations in land and resource management plans, protecting forests and rangelands from unwanted fire, and the use of fire to accomplish management objectives.

Wilderness Fire Management

Early manifestations of the emerging concept of fire management occurred in the National Parks and in National Forest wildernesses. The National Park Service, responding to direction from Leopold and others (1963) initiated a natural fire program at Sequoia and Kings Canyon National Parks in 1968 (Kilgore 1976b). In 1972, the Chief of the Forest Service approved the agency's first wilderness fire management plan, for a portion of the Selway-Bitterroot Wilderness (Mutch 1974). Wilderness fire management programs have grown steadily since their inception. By 1982, some 6,794,000 acres (2 749 532 ha) were included in natural fire programs in 34 National Parks. Between 1968 and 1981, more than 919 unscheduled (naturally ignited) prescribed fires were allowed to burn 133,967 acres (54 216 ha) of parkland. In addition, 183,674 acres (74 333 ha) were treated by 846 scheduled (manager-ignited) prescribed fires (Kilgore 1983).

Wilderness fire management programs are also expanding on the National Forests. During the period 1972-81, some 8,574,577 acres (3 470 131 ha) were included in 33 approved fire management plans for the western National Forests (Regions 1-6). The total includes 5,785,703 acres (2 341 474 ha) of wilderness and 2,788,874 acres (1 128 657 ha) of nonclassified National Forest land. By the end of the 1981 fire season, 369 unscheduled fires had burned a total of 59,380 acres (24 031 ha) since 1972 (Kilgore 1983).

A complete listing of National Park Service-prescribed fire programs and National Forest wilderness fire programs is included in appendix A.

DEFINITION

Wilderness fire management is defined as follows:

Wilderness fire management is the deliberate response to and use of fire through the execution of technically sound plans under specific prescriptions for the purpose of achieving stated wilderness management objectives.

This definition places no preconditions on the practice of fire management. It is meant to encompass all fire-related plans and actions. Often, wilderness fire management is defined only in terms of the reintroduction of fire. Reintroduction implies absence for a period long enough to have become inoperative.

The prior absence or successful exclusion of fire is not recognized as a requirement for wilderness fire management in this report. Some of the legitimate objectives of wilderness fire management are not necessarily related to the prior occurrence and frequency of fire. Examples are visitor safety, protection of private property, boundary considerations, endangered species protection, and habitat management. Also, few wildernesses have experienced total fire exclusion for ecologically significant periods of time. Effective fire control has existed for less than 80 years, a timespan well within the natural fire-free interval of many wilderness vegetation types. Even the most aggressive fire control programs have had notable failures. Many of the fires that have started during periods of very high and extreme fire danger have escaped initial attack and have burned large acreages as fast-spreading, high-intensity, stand-destroying fires. Successful fire control has undoubtedly reduced the acreage burned in many wilderness areas, especially during the past several decades of high-technology fire control. Perhaps the most significant impact of successful fire control has been the nearly total elimination of the easy-to-suppress, slow-spreading, low-intensity surface fire. The vegetative mosaics that resulted over large areas when such fires periodically flared up, ran, and dropped back to the ground in response to changes in weather, topography, and fuel, are generally considered vital to the ecologic integrity of most wilderness ecosystems.

Wilderness fire management is often defined in terms of naturally fire- dependent ecosystems. It is essential that fire-dependent ecosystems be identified and that

wilderness fire management plans reflect such situations where they occur. Wilderness fire management plans can, however, be written for ecosystems that are not fire dependent. Wilderness fire management is an appropriate activity in any wilderness where fire occurs. There are legitimate objectives for wilderness fire management other than the maintenance of fire-dependent ecosystems—for example, the protection from fire of vegetation that is not ecologically dependent on periodic fire.

IMPLICATION

The foregoing definition of wilderness fire management is a functional definition. It relates to the important tasks associated with the practice of wilderness fire management: responding to fire, using fire, and executing plans to achieve wilderness objectives. Many wilderness management objectives were achieved by the former practice of fire control. What, then, distinguishes wilderness fire management from wilderness fire control? One answer to this question might be that fire management implies cost effectiveness; that is, the cost of putting a fire out ought not exceed the value of the resources being protected. This is a valid distinction for lands managed for forest products where market prices can be used to evaluate the resource being protected. It does not adequately explain the difference between fire management and fire control for park and wilderness lands. The difference, according to Van Wagner and Methven (1980), is that wilderness fire management implies vegetation management.

It is important to realize that wilderness fire management is in fact vegetation management. It requires, as Van Wagner and Methven (1980) suggest, a vegetation plan that must be ecologically compatible with what can be achieved by managing fire, either through its application or its exclusion. Wilderness fire management planners must decide what kind of vegetation and associated wildlife is to be maintained, enhanced, and discouraged in the planning area. Planners must then determine the kinds of fires and fire frequencies that will produce the desired vegetation. This is no small task. Nonvegetation-related considerations and constraints will usually result in compromise with the ecologically ideal situation. The ideal should, nonetheless, be described as a basis or reference point for wilderness fire management in a given park or wilderness area.

RESPONSE TO FIRE

Wilderness fire management was defined previously as the **deliberate response** to and use of fire through the execution of technically sound plans under specific prescriptions for the purpose of achieving stated wilderness management objectives. A **deliberate response** to fire is a response that results from careful and thorough consideration of consequences. It is a planned response. There are three general ways to respond to a fire: ignore it, attack it, or allow it to burn according to a predetermined plan. Ignoring a fire, or just letting it burn, is nonmanagement; hence it is not an acceptable response.

Fire attack can be delayed, aggressive, or modified. **Delayed attack** means that attack does not immediately follow discovery. A fire that is discovered at night, for example, might not be attacked until daylight. Delayed attack, once it occurs, can be aggressive or modified. **Aggressive attack** immediately follows discovery and with force sufficient to effect control at the earliest possible time with minimum acreage burned. **Modified attack** is less than aggressive attack. Suppression forces, techniques, strategy, or some combination of these factors are less than those defined for aggressive attack. The "minimum total" concept applies here (USDI Fish and Wildlife Service 1977). For example, additional acres burned might be acceptable if one uses handtools rather than tractors to build fireline in a wilderness area. Delayed and modified attack, like aggressive attack, should be fast, energetic, thorough, and conducted with regard for personnel safety.

Differentiating between delayed, aggressive, and modified attack emphasizes the strategy of fire attack. Another approach is to emphasize fire attack tactics. Using this approach three different fire responses are available: confine, contain, and control (USDA Forest Service 1981a). To **confine** a fire means to restrict it within boundaries that are either predetermined (pre-attack planning) or determined during the fire. To **contain** a fire means to surround it with a fireline, or firelines if spot fires exist, for the purpose of checking the fire's spread. To **control** a fire means essentially to put it out. This involves fireline construction, burning out, cooling hot spots, and other actions that remove any threat of subsequent escape.

The final response to fire is allowing it to burn as a prescribed fire. Allowing a fire to burn according to a predetermined plan is synonymous with the deliberate use of fire because both actions result in a prescribed fire. **A prescribed fire is any fire burning in a predetermined area under predetermined environmental conditions and behaving in a predetermined manner to accomplish a predetermined management objective**. Ignition of a prescribed fire can be either scheduled or unscheduled. A **scheduled prescribed fire** is one ignited by the manager at a predetermined time. An **unscheduled prescribed fire** is one that is ignited as a result of an act of God or unauthorized human activity. The time of such ignition is not known in advance.

The terms "planned ignitions" and "unplanned ignitions" are used by many fire managers instead of scheduled and unscheduled prescribed fires. A planned ignition is defined as a fire started by a deliberate management action, whereas an unplanned ignition is defined as a fire started at random by either natural or human causes. The problem with this terminology is that it implies, for example, that a lightning-caused fire allowed to burn under prescription is unplanned. The fact that a prescription exists, under which the fire is burning, contradicts such an implication. The fire in the above example is, in fact, planned (intended, anticipated, expected). Its exact time and place of occurrence are, however, not known in advance, hence the fire is unscheduled. A basic premise in this report is that all prescribed fires, by definition, are planned.

A prescribed fire can, then, be simply defined as any fire that is burning according to prescription. A prescription is a written direction for the use of a therapeutic or corrective agent. A **fire prescription** is, therefore, **a written direction for the use of fire to treat a specific piece of land.** The directions contained in a fire prescription consist of predesignated criteria that distinguish a prescribed fire from a wildfire.

A **wildfire** is any fire that is not a prescribed fire. It is an unwanted fire. A prescribed fire that deviates irreversibly from prescribed conditions (escapes prescription and cannot be quickly brought back into prescription) becomes a wildfire (also called an escaped fire, see below). Fires that receive delayed or modified attack are wildfires, not prescribed fires.

Wildfires that cannot be successfully controlled by initial attack forces, and prescribed fires that escape prescription and burn as wildfires, are called **escaped fires.** Subsequent action on such fires is based on a plan of action developed as a result of analysis of alternative suppression strategies. An alternative is selected on the basis of total cost effectiveness, public safety, probability of success, protection of property, and the effects of fire and fire suppression on the resources. The results of such **escaped fire analysis** or **situation analysis** are not prescriptions and should not be considered as such. The fire, regardless of management action taken following escaped fire analysis, remains a wildfire.

In the case of an escaped prescribed fire, the decision may be to take the limited suppression action necessary to bring the fire back into prescription. If such action is successful, the fire may regain prescribed fire status since it would again meet the definition of a prescribed fire.

NATURAL VERSUS HUMAN IGNITIONS

The type of ignitions appropriate to achieve fire management objectives should be identified during planning. Wilderness has, of course, an esthetic, spiritual dimension. This is reflected in management policies that place strong emphasis on allowing natural process to function while discouraging or prohibiting the use of anything unnatural. Consequently, wilderness management policies generally encourage the prescribed use of natural ignition agents, such as lightning and volcanic eruptions, to accomplish wilderness fire management objectives and generally discourage or prohibit the prescribed use of unauthorized human ignitions (accidental man-caused fires).

Van Wagner and Methven (1980) make a strong argument for the irrelevancy of mode of ignition. They reason that the effect of any fire is quite independent of how it started; the forest, they point out, certainly cannot tell the difference. They suggest that the only worthwhile distinction is between wanted and unwanted fire as determined by management objectives.

Heinselman (1978) cites concern about safety and concern about unnatural ecosystem effects due to prior fire exclusion as the only legitimate reasons for using scheduled prescribed fires. Safety concerns, according to Heinselman (1978), might dictate that only scheduled prescribed fires "**be used near the wilderness perimeter, near enclaves of development, in very small wilderness in high visitor use areas, and in ecosystems where it is known that natural fires tend to be high-intensity crown fires or severe and fast-moving surface fires.**" Such situations exist in many National Park and National Monument wilderness-type areas. An example of unnatural ecosystem effects due to prolonged fire exclusion would be the situation where unnaturally large fuel accumulations occur in forest stands that experience only low intensity surface fires under a natural fire regime. Unnaturally heavy fuel accumulations can make such stands susceptible to stand-destroying crown fires. Scheduled prescribed fires during moderate burning conditions can reduce fuel accumulations so that subsequent unscheduled ignitions can more nearly play their natural role.

Because parks and wilderness areas are surrounded by boundaries that separate them from areas of different uses, are of limited area, and because their visitors must be protected from uncontrolled fire, a totally natural fire regime is neither possible nor desirable according to Van Wagner and Methven (1980). The objective of perpetuating certain ecosystems within parks and wilderness areas would, they suggest, have to be met by a planned fire regime, probably involving scheduled as well as unscheduled fire. Van Wagner and Methven (1980) feel that the renewal rates and fire cycles would best be set according to the ecology and longevity of the main species, in conjunction with the present age-class distribution and the evidence of fire history. They readily admit that actual locations, numbers, and sizes of fires would be subject to many practical considerations.

Lack of defensible boundaries and typical fire behavior favor the use of scheduled rather than unscheduled prescribed fires to accomplish wilderness fire management objectives in certain northern ecosystems. Alexander and Dube' (1983) cite the example of northern ecosystems characterized by generally flat terrain with continuous fuels, where fires are most often stand-replacing, high-intensity surface or crown fires that defy containment or confinement.

A final situation that often warrants consideration of scheduled versus unscheduled ignitions is the wilderness area traditionally swept by fire originating from a point now outside the wilderness boundary. Fires are now suppressed in the developed lower lying areas that surround many small, high-elevation wildernesses, thereby effectively eliminating any chance of reestablishing a natural fire regime.

Management policies regarding the use of fire to accomplish wilderness fire management objectives are important criteria for planning. Wilderness managers should be aware of these policies before attempting to develop wilderness fire management plans.

PLANNING CONCEPTS

Planning Area

The ideal fire management planning area has distinct topographic boundaries within which any free-burning fire would be naturally contained. The logical planning area for wilderness fire management is the designated

ilderness, National Park, National Monument, or ildlife refuge. Wilderness boundaries often, however, eflect political rather than topographic considerations. Many wilderness boundaries consequently are less than deal for fire management planning.

There are several ways to deal with unfavorable oundary situations. The planning area boundary can be et at favorable topographic, vegetative, or fuel situaions nearest to the wilderness boundary. This solution ight require that some nonwilderness lands be included ithin the planning area, or that some wilderness lands e excluded from the planning area, or both. This aproach may not be acceptable for certain areas. Another olution is to have the planning area and wilderness oundaries coincide and deal with unfavorable boundary ituations when designating fire management units and riting fire management prescriptions. This latter aproach is the one most often used, but in certain situaions the first approach can simplify fire management lanning. A third approach is to establish a fuel break round the area. This approach might be practical when he wilderness is small and the fire break is compatible ith adjoining wilderness values.

Separate fire management plans are sometimes written or a portion of a wilderness. This may be a practical aproach in very large wildernesses that include several opographically distinct portions or when separate porions of a wilderness are managed by different adinistrative units. Such piecemeal or stepwise planning hould be governed by an overall plan developed by all esponsible parties to insure uniform methods, comarable prescriptions, and coordinated fire management ver the entire wilderness.

A final consideration regarding the planning area elates to the use of the term "fire management area." **fire management area** is defined as **one or more arcels of land with common fire management objectives** USDA Forest Service 1978a). This term is being used in wo different ways. In some cases it is used to mean the lanning area, for example, the Selway-Bitterroot Wilderness Fire Management Area. In other cases, the erm fire management area is used to identify portions f the planning area for which specific fire management rescriptions have been written. In many plans, owever, such portions of the planning area are labeled ire management units or zones. In this report, the term fire management area" refers to the planning area. Delineation of fire management units and zones is iscussed in a following section on planning elements.

Planning Context

Wilderness fire management plans cannot be developed n a vacuum. The actions of land management agencies re governed by laws, executive orders, and regulations. The agencies, in turn, formulate policies that further overn the actions of their agents. Many of these laws, egulations, and policies affect wilderness management, ire management, and land management planning. Wilderness fire management plans must reflect the inent of such influences.

PLANNING HIERARCHY

In most land management agencies planning requirements result in a hierarchy of plans. Plans range from broad, national-level documents, to plans that prescribe specific actions on a specific piece of land. The wilderness fire management plan falls at the lower end of the planning hierarchy. As such, it must respond to direction contained in the next higher level plan. This is an important point. Wilderness fire management planners must assure that wilderness fire management issues are properly identified and that contemplated actions are authorized at all appropriate levels of planning.

Wilderness fire management planning for Federal lands is subject to the requirements of the National Environmental Policy Act (NEPA) of 1969 (Public Law 91-190). NEPA requires that a systematic interdisciplinary approach be used in planning and decisionmaking that may affect the human environment. The relationship between NEPA requirements and wilderness fire management planning is illustrated using the Forest Service NEPA process as an example (USDA Forest Service 1981b).

DEVELOPING A FIRE MANAGEMENT PLAN USING THE NEPA PROCESS[2]

The fire management plan is developed using guidance contained in existing multiple-use plans, unit plans, forest land management plans, wilderness management plans, and regional guides, as follows:

NEPA Process Outline

1. Environmental analysis
   - A. Identify issues, concerns, opportunities
   - B. Develop criteria
   - C. Data collection
   - D. Analyze the situation
   - E. Formulate alternatives
   - F. Estimate effects
   - G. Evaluate alternatives
   - H. Identify preferred alternative
2. Documentation
3. Decision
4. Implement and monitor

These are activities the interdisciplinary team, specialists, and line and staff managers will be involved with in developing the environmental assessment for the wilderness fire management plan. The results of the environmental assessment are documented, usually using the standard Council of Environmental Quality (CEQ) format:

Standard CEQ Format

A. Cover sheet
B. Summary
C. Table of contents
D. Purpose of and need for action
E. Alternatives

[2]This section was written by Hugh G. Pangman, Land and Resource Planning Group, Intermountain Region, USDA Forest Service, Ogden, Utah, personal communication, July 1981.

F. Environmental consequences
G. List of agencies, organizations, and persons to whom copies of the document are sent
H. Index
I. Appendix

Other formats useful for planning and decisionmaking may be used, but they must include discussions of items D, E, F, and G of the standard format. The NEPA process outline should not be confused with the CEQ standard format. The NEPA process outline lists the activities involved in an environmental assessment. The CEQ standard format is the format for documenting the results of the assessment. The results of the assessment are documented to show the analytical procedures, considerations, and rationale in arriving at a decision—in this case, the preferred fire management alternative. The wilderness fire management plan is separate from the environmental assessment document, although some information may be taken from the assessment for use in the plan. The information used to select the preferred alternative should, for example, be useful for developing appropriate wilderness fire management prescriptions.

The data requirements for the NEPA process and wilderness fire management plan need not be handled separately. Requirements for each can often be handled simultaneously. As data are gathered, it is necessary to reevaluate preliminary information on objectives, issues, alternatives, and criteria, making additions and refinements as needed.

Key NEPA process requirements and how they relate to the requirements for wilderness fire management planning are discussed below.

Establishing Scope of the Study

The initial phase of planning is devoted to determining the scope of the study. This process is called "scoping" in the jargon of Forest Service planners (USDA Forest Service 1981b). Both NEPA and fire planning requirements are assessed to assure proper data collection and evaluation at the outset. Some major considerations are:

Objectives.—The land management and wilderness management objectives that will guide fire management planning. The management objectives for the area.

Preliminary alternatives.—Fire management prescriptions for different units within the wilderness. (These are general considerations at this point and are refined as data are collected and evaluated.)

Data collection.—This is concerned with two types of data:

1. Data necessary to evaluate fire management alternatives and to complete the fire management plan.
2. Environmental concerns and public involvement (fig. 1).

The scoping system results in a plan to complete the NEPA process and the wilderness fire management plan.

Other requirements of the NEPA process are contained in agency guidelines and are not repeated here. The intent is to show how NEPA and the fire management plan are interrelated. The environmental assessment is completed before the wilderness fire management plan, although portions of the latter will be completed concurrently. The depth of the environmental assessment will be governed by the complexity of the wilderness being studied and the issues involved, and whether an environmental impact statement is needed. A concept labeled "tiering" (USDA Forest Service 1981b) is relevant here. Essentially, tiering means that general matters covered in environmental impact statements for broad plans can be referenced in subsequent statements for narrower plans. Hence, for example, a discussion of fire management policies included in an environmental statement for a National Forest plan can be referenced rather than repeated in a wilderness fire management plan, environmental statement, or assessment.

CHECKLIST OF ENVIRONMENTAL AND PUBLIC INVOLVEMENT FACTORS

____

(Name of Action/Proposal)

The following key describes the disposition of the listed factors:

D. Discussed in assessment.
C. Considered in analysis; no further discussion deemed necessary.

Physical environment

1. ____Geologic hazard

2. ____Climatic

3. a. ____Soil productivity
   b. ____Capability
   c. ____Erodibility of soils
   d. ____Mass failure

4. a. ____Locatable minerals
   b. ____Leasable minerals
   c. ____Energy sources

5. ____Visual resource

6. a. ____Archaeological resources
   b. ____Historical resources
   c. ____Architectural resources

7. ____Wilderness resources

8. a. ____Water quality
   b. ____Streamflow regimes
   c. ____Flood plains
   d. ____Wetlands
   e. ____Ground water recharge
   f. ____Water rights

9. ____Air quality

10. ____Noise

11. a. ____Potential wildfire hazard
    b. ____Role of fire in ecosystem

12. ____Land uses (includes prime farmlands)

13. a. ____Roads
    b. ____Trails
    c. ____Electrical transmissions
    d. ____Communications systems
    e. ____Solid waster management
    f. ____Sanitary waster
    g. ____Rights-of-way
    h. ____Land line

Biological factors

14. a ____Forest (includes diversity)
    b. ____Rangeland management
    c. ____T and E plants
    d. ____Other vegetation types
    e. ____Research natural areas potential
    f. ____Unique ecosystems (other than RNA)

15. a. ____Wildlife population
    b. ____Habitat
    c. ____T and E species
    d. ____Diversity of animal communities

16. a. ____Fisheries habitat
    b. ____Population
    c. ____T and E species

17. ____Outdoor recreation resources

18. ____Economic base

(con.)

Figure 1.—Environmental and public involvement assessment checklist for identifying issues, concerns, and management opportunities.

CHECKLIST OF ENVIRONMENTAL AND PUBLIC INVOLVEMENT FACTOR (con.)

Economic and social factors

19. ____Employment/unemployment

20. ____Housing

21. ____Land use requirements

22. ____Community service requirements

23. a. ____Local government base
    b. ____Special service districts base

24. ____Plans and programs of other agencies

25. a. ____Income sources
    b. ____Income accounts
    c. ____Income distribution

26. a. ____Population numbers
    b. ____Minority composition
    c. ____Distribution and density

27. ____Civil rights

28. ____Local cultures

29. ____Personal security

30. ____Education, cultures, and recreation opportunity

31. ____Legal considerations

32. ____Rights-of-way

33. ____Land line

Public involvement

Attach a list of Federal, State, and local agencies, individuals and organizations interested or involved in the proposa or having information or expertise relative to the project.

Conducted by:______________________________
Name(s)

____
Date

Approved by:______________________________
Name and Title

____
Date

Figure 1.—(con.)

The Plan

The purpose of wilderness fire management planning is to produce a wilderness fire management plan that reflects management direction for the park or wilderness area. A plan is a detailed formulation (systematized statement) of a program of action. The wilderness fire management plan is, therefore, the primary guide for all fire management actions within the planning area, including response to wildfire and the conduct of prescribed fires.

Wilderness fire management plans usually must be reviewed and approved by those not involved in their development. The rationale for the planned actions must, therefore, be documented. Such documentation is best done in a separate report or in associated environmental assessments or environmental impact statements. If the plan and the supporting rationale are presented in one report, the plan should be a separate and distinct part.

FORMAT

The format of wilderness fire management plans is governed by agency requirements, complexity of planned actions, and the creativity of the planner. The important consideration is that the plan be complete, concise, and easy to use.

CONTENT

A wilderness fire management plan should include the following four parts:

1. A brief introduction in which related plans and supporting documents are identified,
2. Explicit fire management objectives,
3. A map of the fire management area, with fire management units and zones clearly delineated and identified, and
4. Planned actions (what, when, who, and if appropriate, how) for:
   a. Responding to fire starts,
   b. Suppressing wildfires,
   c. Analyzing escaped fires,
   d. Monitoring prescribed fires,
   e. Igniting and conducting prescribed fires,
   f. Evaluating fire effects,
   g. Preventing unwanted fires,
   h. Presuppression activities,
   i. Protecting visitors from fire injury,
   j. Informing and involving the public,
   k. Notifying appropriate individuals and agencies and reporting fire actions and activities, and
   l. Reviewing and revising the plan.

WHAT IS AN ADEQUATE PLAN?

Wilderness ecosystems vary in ecological complexity, environmental stability, and fire potential. Agency policy, user patterns and concerns, as well as management direction and opportunities, vary from area to area. All these factors and others determine the adequacy or scope of the wilderness fire management plan.

The environmental analysis should provide a basis for determining the depth or complexity of the planning effort and the resulting plan. The scoping process indicated earlier integrates public participation and coordination, document research and administrative activities and provides a foundation for environmental analysis. The idea is to provide a means for identifying issues early in the NEPA decisionmaking process to ensure thorough analysis and determine the scope or extent of the analysis (USDA Forest Service 1981b).

PLANNING ELEMENTS

Wilderness fire management planning can be separated into six essential elements:

1. Describing fire and ecosystem interactions.
2. Describing special resource and use considerations.
3. Defining fire management objectives.
4. Delineating fire management units and zones.
5. Developing fire management prescriptions.
6. Devising a fire management plan.

The elements are listed in a proper sequence for planning and each depends in part on information developed earlier in the planning sequence. Prescription evaluation and plan revision are not listed as planning elements because they occur after the initial plan has been developed and implemented. These are, however, important elements of the fire management plan. Public involvement is an important part of planning. It is not listed above because it is assumed here that public involvement will occur as part of the environmental analysis process. Subsequent actions directed at public information and involvement are elements of the fire management plan.

Each of the above listed planning elements is defined and discussed in terms of planning approach, information needs, and method of presentation. Selected references to aid wilderness fire management planning are listed in appendix B.

Fire and Ecosystem Interactions

The first step in wilderness fire management planning is to describe how the physical and biological characteristics of planning area ecosystems have been and might be affected by fire, the absence of fire, and fire suppression actions. Interactions between fire and other ecosystem components can be identified by delineating and describing planning area ecosystems in relation to their fire situation. Consider this to be a three-step process: (1) classify, describe, and map area ecosystems; (2) describe the fire situation; and (3) identify and describe significant fire-related interactions. (In practice these three steps may not be so clear cut.)

ECOSYSTEM CLASSIFICATION

Classification involves grouping similar objects and separating dissimilar objects. Classification brings order to our thinking and communication by systematically naming the objects being classified and showing the relationships among them. The purpose of classification for land management is to organize, communicate, and collect information for decisionmaking.

Identification and delineation of wilderness ecosystems is important because such classification provides (1) a basis for inventorying current resources, (2) a means of transferring experience and knowledge about a studied area to a similar but unstudied area, (3) a framework for assessing local management opportunities and predicting the outcomes of treatments or actions, and (4) a means for communicating among managers, researchers, and the public (Frayer and others 1978).

Ecosystem classification terminology, methods, and approaches are reviewed and evaluated by Pfister (1977) and Bailey and others (1978). Another useful reference is the Guide to Land Cover and Use Classification Systems employed by western governmental agencies (Ellis and others 1977). Additional references are listed in appendix B.

INTEGRATED CLASSIFICATION SYSTEMS

Wilderness fire management planning needs are best served by an integrated approach to ecosystem classification. Enlightened decisions relating to fire use, fire exclusion, and fire control require knowledge of soils, current and potential vegetation, and landform. A fourth component, water, may be equally important in many wilderness areas. According to Driscoll (1980), agency leaders of the Bureau of Land Management, Fish and Wildlife Service, Forest Service, Geological Survey, and Soil Conservation Service endorsed a four-component classification system to be used for renewable resource inventories and assessments (Driscoll and others 1978). The hierarchical components are vegetation, soil, landform, and aquatic (water).

The major four-component ecosystem classifications described in the literature are biophysical land classification (Lacate 1969), ECOCLASS (Corliss and others 1973), modified ECOCLASS (Buttery 1978), and ECOSYM (Henderson and others 1979). To date, none of these classifications have been used in conjunction with wilderness fire management planning efforts. This is mostly due to the still developmental nature of the systems.

Ecosystem classification based on integration of three components has been and is being used for wilderness fire management planning in the Forest Service Northern Region. The Clearwater National Forest portion of the Selway-Bitterroot Wilderness was, for example, stratified into ecological land units (ELU's) as a first step in fire management planning (Fiman and Thomas 1979). An ELU is defined as an identifiable parcel of land having similar characteristics of landform, soils, and potential vegetation. The ELU in this example is comparable to the land type association (LTA) of the Land Systems Inventory (Wertz and Arnold 1972; Wendt and others 1975; USDA Forest Service 1976). The land system is outlined in figure 2.

A recent land system inventory of the Scapegoat and Danaher portion of the Bob Marshall Wilderness (Flathead, Lolo, Lewis and Clark, and Helena National Forests) in Montana is another example of the application of the land system for wilderness fire management planning (Holdorf and others 1980). Figure 3 is a land type association (LTA) map developed for a portion of the planning area. Land type associations are based on associations of habitat types, soils, and landforms (see fig. 2). Mapping units are designed to produce analysis units with similar response to wilderness management. The principal management practice considered is fire management, but properties influencing wildlife habitat, watershed behavior, and wilderness recreation were also considered.

THE FIRE SITUATION

The second step in defining interactions between fire and other ecosystem components is to describe the fire situation for the planning area. "Fire situation" is an arbitrary term used here to identify fire's historic role, the current potential for fire, and the probable effect of present and future fire on planning area ecosystems.

FIRE HISTORY

A requirement of wilderness management is to preserve natural conditions. The wilderness fire management planner must therefore understand the role played by fire, if any, in establishing and perpetuating natural conditions. The planner must also determine the probable effect, if any, of past fire exclusion. To understand the role fire has played, planners must determine the fire history of the planning area.

Postglacial Period

Methods for investigating fire history vary according to the time periods of interest. Evidence of fire and its role in determining the composition of forest vegetation during the period following the retreat of glaciers in northern and mountain regions of North America can be obtained from lake and bog sediment cores (Swain 1973; Mehringer and others 1977; Schweger 1978). Wilderness fire management planners rarely have the resources to conduct studies of this type. They should, however, review the ecological, paleoecological, paleobotanical, geological, and related literature for studies that might pertain to planning area ecosystems.

Settlement Period

Journals of early explorers and settlers and investigations of aboriginal fire practices are important sources of fire history. Examples of such sources are Lutz (1959) for Alaska, Reynolds (1959) and Kilgore and Taylor (1979) for the Sierra Nevada region, Lewis (1977, 1978) for northern Alberta, Barrett (1980a, 1980b) for the Northern Rockies, and Shinn (1980) for the inland Pacific Northwest. Such information is usually not detailed enough to develop a fire history for a specific area. The use of early government land survey records to estimate the proportion of stands killed by fire in a 15- to 25-year period preceding the survey for vast areas of presettlement forest is discussed by Lorimer (1980).

Many investigators have developed detailed fire histories dating back to A.D. 1700 or earlier, which actually predates settlement in many areas. The investigators used historical records and techniques for reading tree rings and determining stand origin analysis. Heinselman (1973) describes these techniques and cites their use in developing a fire history for the Boundary Waters Wilderness.

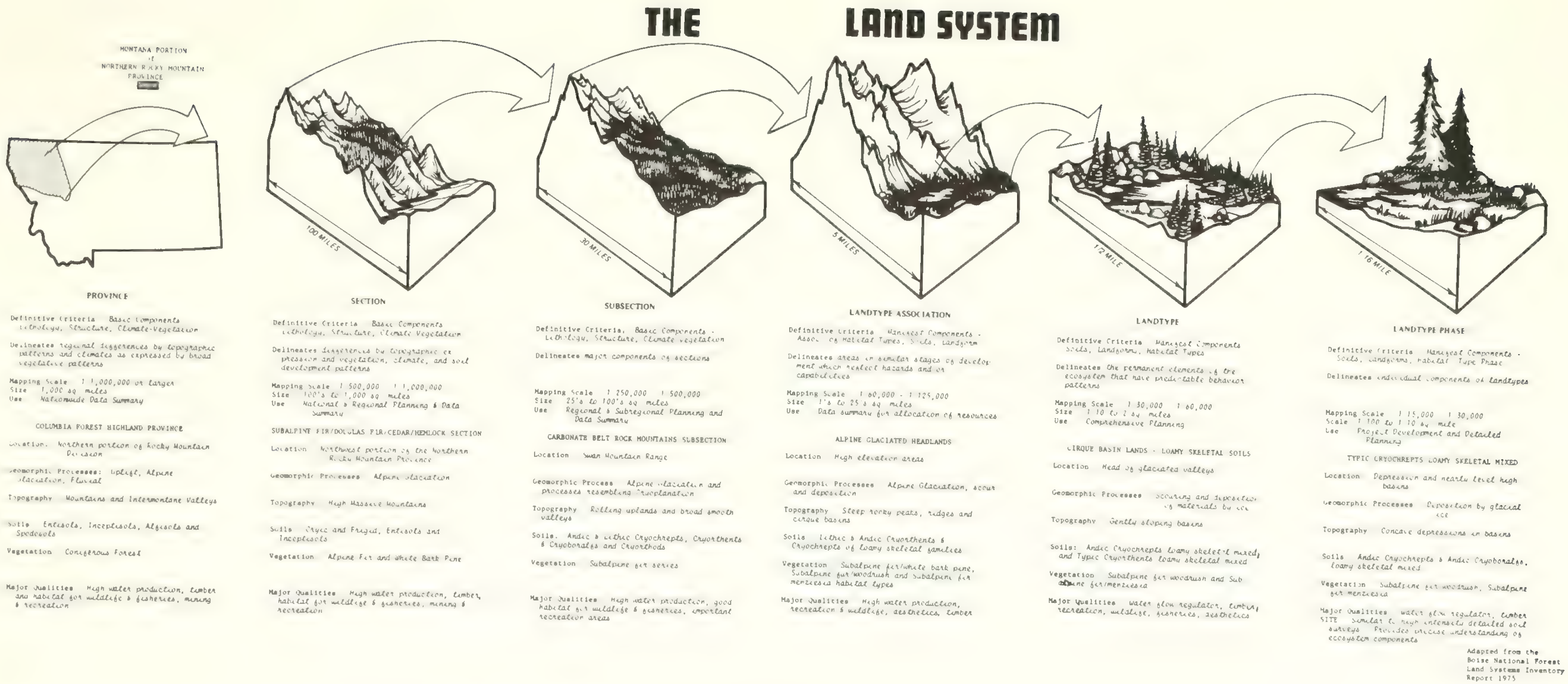

Figure 2.—The land system (sources: USDA Forest Service 1976; Wendt and others 1975).

Figure 3.—Land type association map for a portion of the Scapegoat and Bob Marshall Wilderness areas, Flathead, Lolo, and Lewis and Clark National Forests (source: Holdorf and others 1980). Land types are: I, forested flood plains; Ia, wet, grass-sedge meadows; Ib, grass and forested stream terraces; II, glacial cirque basins; III, forested ground moraine; IIIa, forested steep lateral moraine; IV, slump land; Va, forested high elevation ridges; Vb, forested smooth residual slopes; Vc, forested moderately dissected residual slopes; Vd, forested and grassland smooth residual slopes; VI, peaks and alpine ridges—sparsely vegetated rock land; VII, forested, cool aspect break lands; VIII, forested, warm aspect break lands.

LAND TYPE ASSOCIATION MAP

DANAHER-SCAPE GOAT AREA

USFS REGION 1

SCALE: 1:63,360 MAY 1979

Arno and Sneck (Davis) (1977) describe a step-by-step method for determining fire history in coniferous forests of the Mountain West. This method is designed to answer the following questions: What were the (1) average, minimum, and maximum intervals between fires in various forest habitat; (2) sizes and intensities of fires; (3) effects of past fire on forest vegetation, particularly stand composition and age class structure; (4) effects of modern fire suppression? Arno and Sneck (Davis) (1977) provide instructions for study area selection, field reconnaissance, sampling fire- scarred trees, and analysis of fire scars and stand data.

Alexander (1979, 1980) and Mastrogiuseppe and others (1983) have developed and maintained a bibliography of fire history studies. This bibliography is a useful source for identifying available fire history information in North America.

Fire Control Period

Most fires that have occurred since the advent of organized fire control are documented. These fire reports are the major source of fire history information for the period starting about 1900. Maps showing fire locations and the boundaries of large fires that have occurred during the past 80 to 100 years are maintained by some fire control agencies as part of periodic fire planning. These maps are excellent sources of fire history information.

Fire history techniques and fire histories for specific parks and wilderness areas are referenced in appendix B.

FIRE POTENTIAL

Fire potential is an ecosystem's capability for fire. The traditional concepts of fire risk, fire hazard, and fire danger are incorporated within the concept of fire potential. The important determinants of fire potential are probable fire occurrence, the fire environment, and probable fire behavior. Fire enrivonment refers to the conditions, influences, and modifying forces that control fire behavior (Countryman 1972). The fire environment is composed of three interacting influences: fuels, weather, and topography.

Fire Occurrence

Probable fire occurrence is, for lack of a better method, usually based on past fire occurrence. Individual fire reports are the primary source of information on past fire occurrence. Most fire control agencies have such reports for all known fires since the early 1900's. Regionwide summaries of fire occurrence for wilderness areas, primitive areas, and wilderness study areas in the Northern Rocky Mountains and in the Southwest are presented by Barrows and others (1977) and by Barrows (1978, 1979).

A useful expression of lightning fire occurrence is lightning fire density (fires per million acres per year; fires per km^2/year) by such ecosystem characteristics as cover type and elevation. Fire density values should be derived using the normalizing technique suggested by Bevins and Barney (1980) and Bevins and Jeske (1978).

Stocks and Hartley (1979) summarized fire occurrence data for Ontario. Their summary includes probability of fires occurring under different levels of fire danger and a map showing fire densities.

Man-caused fire probabilities are more difficult to determine than are lightning fire probabilities. Past occurrence patterns are relevant but are sensitive to fire prevention programs, trail construction and maintenance, and other such factors that affect people's actions and access.

Roussopoulos and others (1980) have developed a prototype National Fire Occurrence Data Library (NFODL). The NFODL facilitates nationally uniform editing, storage, retrieval, and analysis of wildland fire report data. It is maintained at the USDA Fort Collins Computer Center and now contains all USDA Forest Service Individual Fire Report data since 1970. Provisions have been made to accommodate data from other agencies. The NFODL can be a very useful aid for analyzing fire report data as a basis for predicting future occurrence patterns.

Fire Environment

The fire environment is composed of three interacting influences: fuels, weather, and topography.

Topography includes such elements as slope, aspect, elevation, and configuration. Topography is an element of landform. Topographic information will, consequently, be available if landform analysis was performed as part of ecosystem classification. The primary sources of existing topographic information are aerial photos and topographic maps.

Alexander and Woods (1978) discuss many of the considerations involved in preparing a fire weather climatology for park- and wilderness-type areas. Weather elements influencing planning area ecosystems must be characterized using historic weather data. FIREFAMILY, a computer program that uses historic weather data to predict fireline fire management needs, can be a useful fire management planning tool (Main and others 1982). Wilderness fire planners should summarize weather and climatic data according to the guidelines presented by Finklin (1983).

Fuels occupying planning area ecosystems should be characterized in terms of kind, size, amount, location, and areal extent. Methods used should be consistent with desired precision, which in turn should depend on the cost or consequences of an incorrect fuel-related decision (Hamilton 1978). Methods for characterizing fuels include actual inventory, photoguides, known relationships from existing data, and fuel models.

Brown and others (1982) present procedures for inventorying living and dead surface vegetation.

Photoguides for estimating loadings of natural fuels have been developed for forest types in the Pacific Northwest (Maxwell and Ward 1980a, 1980b), for the Southern Cascades and Northern Sierra Nevada (Blonski and Schramel 1981), and for the Northern Rocky Mountains (Fischer 198la, 198lb, 198lc, 198ld). Where applicable, the guides can be used to obtain reasonable estimates of fuel loads for less than the cost of fuel inventory. At the same time they provide visual references of fuel situations that can be used when deciding appropriate actions on fire starts.

Known relationships from existing fuel inventory data can be obtained for some forest types from a prototype National Fuels Inventory Library (NFIL) developed by Bevins and Roussopoulos (1980). This library is maintained at the USDA Fort Collins Computer Center.

Summaries and analyses of existing fuel inventory data for local areas have been published.

A final method for characterizing fuels is the use of fuel models. The most popular fuel models are those used with the NFDRS (Deeming and others 1977; Anderson 1982).

Albini (1976) cautions that the accuracy with which any particular situation in the field is reproduced by one of these stylized models is highly variable. A recent innovation that may reduce this variability is the BEHAVE computer system (Andrews 1983). BEHAVE provides a capability for trained field personnel to construct fuel models tailored to a site.

Fire Behavior

Probable fire behavior depends on the likely interactions between elements of the various fire environments existing in the planning area. The first step in characterizing probable fire behavior is to identify planning area ecosystems that have similar topography and fuels. Ecosystems may also be stratified according to weather if such site-specific data are available. The next step is to estimate probable fire behavior for each ecosystem or group of ecosystems for the range of probable weather conditions, or for some specific benchmark weather condition.

Estimating probable fire behavior is a critical fire management planning task. It is also a demanding and relatively complex task. Rothermel (1983) has recently produced a manual in which he documents state-of-the-art procedures for estimating the rate of forward spread, intensity, flame length, and size of fires burning in forests and rangelands. Rothermel's procedures have become the generally accepted standard for wildland fire behavior prediction. Rothermel's procedures plus a capability of building site-specific fuel models are packaged in the BEHAVE computer system (Andrews 1983). Although neither system was designed for long-range planning, both can use expected weather or climatological data from an area that, when coupled with an assessment of the fuels and site conditions, can give appraisals of the expected fire behavior.

The National Fire-Danger Rating System (NFDRS) may also be used for planning wilderness fire potential and for monitoring fire potential as the season develops.

The NFDRS contains two components and an index that have been used for estimating potential fire behavior. The spread component (SC) integrates the effect of wind, slope, and fuel to predict the forward rate of fire spread. Fuel is characterized by fuel models. The energy release component (ERC) indicates the potential amount of energy that can be released in a passing fire. The ERC reflects the effect of fuel moisture on fire intensity. The SC and ERC combine in the NFDRS to form the burning index (BI). The BI is designed to be a measure of the difficulty of containing a single fire. The BI has been interpreted in terms of fire behavior, controllability, flame length, and fireline intensity (table 1).

There are several subjective methods for estimating fire behavior. The methods are either based on experienced judgment or require experienced judgment in their application, or both. Two such methods are associated with previously described fuel appraisal photoguides.

Maxwell and Ward (1980a, 1980b) include an assessment of fire behavior and suppression difficulty for each photo included in their guide. These assessments are based on fire model predictions for the measured fuel situation shown in the photos.

The photoguides developed by Fischer (1981a-d) provide estimates of rate of spread, intensity, torching, crowning, resistance to control, and overall fire behavior potential. Estimates are made for average bad-day conditions, which are identified in the guides. Fire managers and researchers with experience in prescribed fire and fire control assigned adjective ratings for each fire behavior element according to a uniform set of definitions. Both NFDRS and stylized fuel models are assigned to each photo in these guides.

Fahnestock (1970) developed two keys for appraising fire behavior based on fuel characteristics. One key rates relative potential rates of spread; the other rates crowning potential. Both keys require experienced judgment in use and in interpretation of results.

Another approach to evaluating fire behavior potential is simply to apply knowledge of past fire behavior in specific fuel and vegetative types under known burning conditions. This was the approach used to evaluate potential fire behavior for Fischer's (1981a-d) photo series

Table 1.—Burning index interpreted in terms of fire behavior, controllability, and fireline intensity (source: Deeming and others 1977)

Burning index	Fireline intensity		Flame length		Narrative
	Btu/s/ft	*kw/m*	*Ft*	*m*	
0–28	0–50	0–173	2.8	0.85	Most prescribed burns are conducted in this range.
38	100	346	3.8	1.16	Generally represents the limit of control for manual attack methods.
78	500	1 730	7.8	2.38	The prospects for control by any means are poor above this intensity.
96	700	2 421	9.6	2.93	The heat load on people within 30 feet of the fire is dangerous.
108	1,000	3 459	10.8	3.29	Above this intensity, spotting, fire whirls, and crowning should be expected.

An overall evaluation of fire potential requires joint consideration of probable fire occurrence and probable fire behavior, given an occurrence.

There is no established method for expressing overall fire potential in a manner that adequately reflects the interrelationships involved. Statistical methods for dealing with probabilities do exist and have been applied to fire management problems (Hirsch and others 1979). Such methods have yet to be worked out for evaluation of fire potential as used herein.

Fire potential can be expressed and mapped as an adjectival rating, or rather two adjectival ratings; one for fire occurrence probability and one for probable fire behavior for some benchmark set of weather conditions. Any of the schemes described for estimating probable fire behavior can be used to derive adjectival ratings of low, moderate, high, and extreme fire behavior. A similar rating can be derived for probable fire occurrence by arbitrarily defining adjectival levels of low and high occurrence. Such an approach would provide eight classes of fire potential ranging from a "low occurrence - low fire behavior" class to a "high occurrence - extreme fire behavior" class.

Techniques for characterizing an area's fire occurrence, fire environment, and probable fire behavior are referenced in appendix B.

An adequate evaluation of fire potential allows the planner to answer the following kinds of questions about the planning area:

1. How many fires are likely to occur in a season and when?
2. What kind of fuels exist and where?
3. What kind of weather conditions are likely to occur at different times during the burning season?
4. How might various fuels burn under the range of likely weather conditions?

Information sources, data collection techniques, and analytical methods that can help answer such questions are included in appendix B.

FIRE EFFECTS

Wilderness fire management planners need to identify fire effects that pertain to planning area ecosystems. To be useful, fire effects must be related to ecosystem classification and fire severity. Emphasis should be on characterizing the general effects of fires of varying severity on plant and animal succession and watershed properties. Fire effects information sources are included in appendix B.

Summarizing Fire Effects

Fire effects information should be summarized in a way that reflects the ecosystem classification used for the planning area and the information needs of the planning effort. Effect of fire on vegetation, for example, can be summarized according to habitat type or cover type to show the effects of fire on plant succession. Habitat type fire groups (Davis and others 1980; Fischer and Clayton 1983; Crane 1983) provide a convenient way to group sites according to a similar response of tree species to fire and a similar postfire succession. Successional diagrams can be constructed for each fire group to show basic trends in structural changes and tree species succession (Kessell and Fischer 1981). The diagrams also show general responses to fires of different intensities and different stages of recovery from the last fire.

The effect of fire on soils and water is mostly a function of fire severity, slope, soil characteristics, geology, and vegetative cover. Soil and watershed specialists have developed rating systems to predict watershed response to fire and other disturbances based on such criteria as surface erosion hazard, mass wasting potential, stream channel stability, land and stream recovery potential. Examples of such rating systems are provided by Boyer and Dell (1980) for the Pacific Northwest and by Rosgen (n.d.) for the Northern Rockies. Fire management planners should enlist the aid of local soils and watershed specialists to identify and apply local rating systems when applicable. Results of soil and watershed rating systems should be compared to relevant fire effects research to assure validity. Table 2 includes ratings for vegetative and hydrologic recovery rate and erosion hazard for the Scapegoat and Bob Marshall Wildernesses, Mont. Settergren (1969) has summarized much of the existing research on effects of fire on wildland hydrology.

Fire's effect on wildlife is most often manifested through the fire-induced change in vegetation, i.e., habitat. Models designed to predict postfire plant succession can, therefore, be interpreted in terms of wildlife habitat to yield postfire wildlife succession models. Wilderness fire management planners should enlist the aid of wildlife specialists to assist in this task.

Smoke dispersion depends on windspeed and direction and atmospheric instability. Furman's (1979) PRESCRIB and MERG 3 computer programs were designed to provide estimates of the probable occurrence and persistence of poor smoke dispersal conditions. Smoke production depends on fuel loading and the moisture content of the fuels. Wet fuels produce more smoke than dry fuels. Consequently, preseason and postseason fires will usually result in more smoke than those that occur during the fire season.

Mutch and Briggs (1976) discuss smoke as a factor in the maintenance of natural ecosystems.

SUMMARY OF INTERACTIONS

Summarizing fire and ecosystem interactions requires setting down the major elements of the fire situation identified for each ecosystem. Such a summary will aid in identifying important differences in fire history, fire potential, and fire effects (tables 2 and 3). These differences can, in turn, be valuable aids for developing fire management objectives, delineating fire management units and zones, and prescribing appropriate fire management actions.

Holdorf and others (1980) use a series of aerial oblique photos to illustrate planning area ecosystems (land type associations) in the Scapegoat and Bob Marshall Wildernesses, Mont.

Five of the 14 land type associations identified by Holdorf and others (1980) are delineated on the photo in figure 4.

Table 2.—Characterization of the effects of fire on watershed in the Bob Marshall and Scapegoat Wildernesses: Flathead, Lolo, Lewis and Clark, and Helena National Forests, Mont. (source: Holdorf and others 1980)

LTA[1]	Landform	Slope class	Elevation	Dominant aspect	Dominant habitat types	Vegetative fire group[2]	Vegetative-hydrologic recovery rate[3]	Fire-induced erosion hazards[4]
			Feet					
I	Forested flood plains	0–10	4,500–5,500	None	ABLA/LIBO,	9	Rapid	Low
Ia	Wet, grass-sedge meadows	0–10	4,500–5,200	None	Willow-Sedge-Rush	0	Rapid	Low
Ib	Grass and forested stream terraces	0–10	4,800–5,200	None	ABLA/VACA, FESC/FEID	7 & 0	Rapid	Low
II	Glacial cirque basins	0–40	6,000–7,500	N & E	ABLA-PIAL/VASC, ABLA/LUHI	10	Slow	Severe (b)
III	Forested ground moraine	0–25	4,600–5,600	None	PICEA/VACA, ABLA/VACA	7	Rapid	Low
IIIa	Forested steep lateral moraine	5–60	5,500–6,800	None	ABLA/MEFE, ABLA/XETE	9	Moderate	Moderate (a)
IV	Slump land	0–40	5,000–7,500	None	ABLA/XETE, ABLA/MEFE	9	Moderate	Moderate (a)
Va	Forested high elevation ridges	0–40	6,800–8,000	None	ABLA-PIAL/VASC, ABLA/LUHI	10	Slow	Severe (b)
Vb	Forested smooth residual slopes	25–60	5,000–6,800	N & E	ABLA/XETE, ABLA/MEFE	7 & 9	Moderate	Low
Vc	Forested moderately dissected residual slopes	25–60	5,000–6,800	N & E	ABLA/XETE, ABLA/MEFE	7 & 9	Moderate	Low
Vd	Forested and grassland moderately dissected residual slopes	25–60	5,000–6,800	S & W	PSME/FEID, FESC/FEID	5	Slow	Low
Ve	Forested and grassland smooth residual slopes	25–60	5,000–6,800	S & W	PSME/FEID, FESC/FEID	5	Slow	Low
VI	Peaks and alpine ridges—sparsely vegetated rock land	60 +	6,000–10,000	All	ABLA-PIAL/VASC + SCREE	10 & 0	Slow	Low
VII	Forested, cool aspect break lands	60 +	5,500–7,500	N	ABLA/MEFE	9	Moderate	Moderate (a
VIII	Forested, warm aspect break lands	60 +	5,500–7,500	S & W	PSME/FEID, CARU PSME/SYAL + AF/XETE + SCREE	0	Slow	Low

[1]LTA = land type association.

[2]Davis and others 1980.

[3]**Vegetative-hydrologic recovery:** The rating is based on estimated rates of secondary succession for habitat types occurring within the land type association. Recovery is assumed to be a 10 percent or less increase in water yield compared to mature forest cover. The rating considers factors such as evapotranspiration rates, interception losses, and redistribution of snow in forest openings. Rating definitions: rapid—less than 40 years; moderate—40 to 60 years; slow—60 or more years. Refer to Rosgen (n.d., p. 10).

[4]**Fire-caused accelerated erosion hazard:** This is a rating of the probability of fire-induced accelerated erosion. Rating considers water, dry creep and mass movement erosion. The ratings are defined as follows: low—either there is no hazard or the probability is so low that it need not be considered in planning. Generally any accelerated erosion which occurs following fire will not have a measurable effect on water quality. Moderate—accelerated erosion may increase sediment load of streams but not sufficiently to affect downstream fisheries or recreation uses. Some degradation of the esthetic quality of streams occurs and if reservoirs occur downstream, accelerated sediment deposition is an added cost. High—accelerated erosion following fire produces dramatic increases in sediment loads of streams with high probability of adverse effects on fisheries and recreation uses. Sedimentation of reservoirs is an added cost.
The rating assumes a fire intense enough to kill overstory vegetation and consume litter and duff layers on most of the burned area. Fires of less intensity can and do occur but will not appreciably affect erosion rates.
Erosive processes considered in making ratings were: (a) slumps and debris avalanches; (b) streambank erosion caused by increased water yield.

Table 3.—Examples of summarizing fire and ecosystems interactionsfor a portion of the Selway-Bitterroot Wilderness (SBW) (source: Fiman and Thomas 1979)

ELU[1] name and number	Acres	Lightning load	Micro-climate	Aspect	Fire potential	Fire cycle	Fire season	ELU name used other SBW fire plans
						Years		
ELU No. 1, strongly glaciated uplands	56,450	3.1/yr	Cold-moist	N & E	Low	100–250	Middle July-Middle September	Subalpine
ELU No. 2, frost-churned uplands	101,841	4.0/yr	Cold-moist to cold-dry	S & W all	Medium Medium	100–200	July-September	Rolling landforms Moose Ck Lodgepole ELU West Fork RS
ELU No. 3, north-facing trough walls	24,799	1	Cold-dry	N	High	150–200	July-September	(Moose Creek, West Fork) North slope communities
ELU No. 5, south-facing scoured walls	34,114	1	Cold-dry	S	High	15–75	July-September	Ponderosa pine/ Douglas-fir South slope
ELU No. 6, wet uplands	5,740	1	Cold-wet	all	Low	100–200	July-September	—
ELU No. 7, riparian	16,076	1	Cold-wet	all	High-low	300–400	July-September	Stream bottom grand fir/cedar Stream bottom
ELU No. 8, stream break-lands, south exposure	15,929	1	Warm-dry	S	High	15–75	May-September	Ponderosa pine/ Douglas-fir South slope
ELU No. 9, stream break-lands north exposure	5,951	1	Cool-moist	N & E	Medium	150–250	July-September	North slope communities
ELU No. 10, wet draws and swales	1,414	0	Cool-moist	all	Low	150–250	July-September	—
ELU No. 11, colluvial slopes	2,560	0	Cool-moist	N & E	Low	150–250	July-September	North slope communities

[1]Ecological land unit (ELU) designation is roughly equivalent to land type association (LTA) as used herein.

Sugarloaf Mtn.

LTA IV : Slump Land

LTA Va: Forested High Elevation Ridges

LTA Vb: Forested Smooth Residual Slopes

LTA Ve: Forested & Grassland Smooth Residual Slopes

LTA VI : Peaks & Alpine Ridges - Sparsely Vegetated Rockland

Figure 4.—Five of the land type associations identified in the Scapegoat and Danaher portion of the Bob Marshall Wilderness, Flathead, Lolo, Lewis and Clark, and Helena National Forests, Mont. (source: Holdorf and others 1980).

Kessell (1976a) used a gradient modeling approach to summarize fire and ecosystem interactions. He developed the Glacier National Park Basic Resource and Fire Ecology Systems Model, which links four major fire management components: (1) a terrestrial site inventory coded from aerial photographs that offers 33 ft (10 m) resolution; (2) gradient models of vegetation and fuel that derive quantitative stand compositional data from the parameters stored in the coded inventory; (3) a fuel moisture and microclimate model that extrapolates base station weather data to remote sites using the parameters stored in the inventory; and (4) fire behavior and fire ecology models that integrate the data from the inventory and models to calculate real-time fire behavior and ecological succession following a fire (Kessell 1976b). To adequately summarize fire and ecosystem interactions, the planner should answer the following questions for each ecosystem identified based on its fire situation:

1. What is the natural role of fire?
2. How has fire suppression affected physical and biological characteristics?
3. When, where, and what kind of fires are likely to occur?
4. Are fires likely to intrude from an adjoining area?
5. How will future fires of varying intensity affect physical and biological characteristics?
6. How will fire exclusion affect physical and biological characteristics?
7. What environmental impacts are associated with various fire suppression methods and fire management strategies?

Special Resource and Use Considerations

Most wildernesses have unique features and permitted uses that require special consideration when planning fire management. Such areas should be identified, described, and mapped. This is often done in a higher level plan. Areas requiring special consideration include:

1. Ecological, archeological, geological, and other features of scientific, scenic, or historical value.
2. Rare, endangered, and threatened plant sites and animal habitats.
3. Administrative sites and improvements.
4. Designated recreation sites.
5. Grazing allotments.
6. Oil, gas, and mineral exploration sites.
7. Non-Federal land within and immediately adjacent to boundaries.

Appropriate specialists (archeologists, geologists, ecologists, wildlife biologists, etc.) should assist in identifying special areas and in appraising probable effects of fire, fire exclusion, and fire suppression.

The important question to be answered is: How might fire or the absence of fire affect ecologic, archeologic, geologic, and other features of scientific, scenic, historical, or cultural value?

Fire Management Objectives

Wilderness fire management objectives state the planned measurable results desired from a wilderness fire management program. The overall goal toward which wilderness fire management objectives should be aimed is the preservation and enhancement of the wilderness resource through a well-planned and well-executed fire protection and use program that is ecologically sound and cost effective.

Fire management objectives for a specific wilderness planning area depend on the fire-ecosystem interactions, special resource and use considerations identified for the area, and the wilderness management objectives set forth in the wilderness management plan or other appropriate land management plan. As indicated earlier, relevant fire management policy and other direction should be reflected in the wilderness management objectives. If for some reason they are not, they should also be identified and used as a basis for defining specific wilderness fire management objectives.

Defining specific fire management objectives is the critical element in wilderness fire management planning. When this has been done, the remaining planning effort is devoted to developing criteria and devising methods that assure accomplishment of the fire management objectives.

Fire management objectives should be clearly stated and explicit. They should encourage fire use where such use is ecologically sound and beneficial to management objectives. Conversely, fire protection should be required where necessary to assure visitor safety, protect private property, and to avoid undesirable environmental impacts and detrimental effects in terms of the wilderness resource. The following is a list of management goals and associated objectives relevant to many wilderness-type areas:

Goals	Objectives
Allow fire to achieve its natural[3] role.	1. Perpetuate naturally occurring plants and animals. 2. Perpetuate natural vegetative patterns. 3. Maintain "natural" fire regime.
Use fire to accomplish desired resource management objectives	1. Restore fire where exclusion has had adverse effects. 2. Create, maintain, or enhance habitat for threatened, endangered, or desired plants and animals.
Protect life, property, and resources from unwanted fire.	1. Protect visitors. 2. Protect scientific, scenic, or historical values. 3. Protect recreation, administrative, and other imposed sites. 4. Protect intermingled and adjacent nonwilderness lands.
Avoid unacceptable effect of fire and fire suppression.	1. Maintain acceptable air quality. 2. Use low impact fire suppression techniques. 3. Prevent unauthorized man-caused ignitions. 4. Avoid prescribing fire of "unnatural" severity.

[3]Natural means being in accordance with and determined by nature; untouched by the influences of civilization and society.

This list does not exhaust the range of possible wilderness fire management objectives, and some of the listed objectives may be inappropriate for a given wilderness area. But identification of objectives is the first step in fire management. Fire management objectives should flow from the land management plan for the wilderness and should, consequently, be largely developed by wilderness managers and resource specialists. Fire management objectives should include such specifics as what, where, when, and so on. If, for example, an objective is to maintain favorable habitat for a rare species, the objectives should identify the species, describe favorable habitat conditions, and tell how much habitat needs to be maintained.

Fire Management Units and Zones

Fire management area (FMA) is, as indicated earlier, the term used to denote a planning unit. Fire management unit (FMU) and fire management zone (FMZ) are terms used to denote parts of a fire management area. Fire management unit and fire management zone are often used as synonyms. They are not so used here. **A fire management unit is a distinct part of the fire management area that can be recognized and mapped from its external features.** A particular drainage within a fire management area is an example of a fire management unit. It is, in a sense, a mini-fire management area. **A fire management zone refers to all the land within a fire management area that has in common a particular characteristic.** The shared characteristic can be physical, biological, or use-related; for example, all the land above 9,000 ft (2 743 m) or all land that comprises critical grizzly bear habitat or grazing allotments.

Fire management units and zones are delineated to help the planner write fire management prescriptions and develop and implement fire management actions. They enable the planner to focus on a particular piece or type of land and make integrating fire-ecosystem interactions, special resource and use considerations, and fire management objectives manageable.

The nature of the fire management area and the associated fire management objectives should determine whether fire management units, fire management zones, or both units and zones are delineated. Fire management zones are often used to divide a small fire management area that has relatively uniform characteristics. Fire management zones are also appropriate when fire management objectives are few and result in relatively simple fire prescriptions. Fire management units are often appropriate for dividing large fire management areas of diverse characteristics and for areas of any size where fire management objectives vary and require complex prescriptions. Both fire management units and fire management zones may be required in certain situations. A likely case would be a large fire management area requiring division into many large fire management units, each of which has several fire management objectives and special resource and use considerations.

Stratification of a wilderness fire management area into fire management units (FMU) and fire management zones (FMZ) depends on area size; physiognomy; ecosystem diversity; the fire situation; presence of unique features, special uses, and improvements; land ownership patterns; and fire management objectives.

FIRE MANAGEMENT UNITS

Fire management units should be rather large homogeneous areas with boundaries that are natural barriers to fire spread or that at least provide a reasonable chance for fire containment. Mountain wildernesses can usually be divided into fire management units that correspond to major drainage patterns. Planning areas that lack a pronounced topography can be divided into units based on past fire patterns, major changes in vegetation or fuel type, or other appropriate criteria. Based as they are on external features, fire management units can easily be located on aerial photos.

Wilderness fire management planning and implementation can be based on a fire management unit basis if management units are delineated early in the planning process. Planning can then proceed one unit at a time.

FIRE MANAGEMENT ZONES

A fire management zone consists of one or more parcels of land within the planning area; these parcels have common fire management objective(s) that can be satisfied by a common fire management prescription. Fire management zones are usually composed of similar ecosystems having similar fire situations. They may, however, also reflect common special features or use considerations.

Delineating fire management zones is a synthesizing process. The fire management planner must translate wilderness fire management objectives into planned management responses to fire on specific pieces of land within the planning area.

A first step in identifying fire management zones is to aggregate lands on an ecological basis. The next step is to scrutinize the fire situation in ecologically similar units. Probable fire behavior and associated fire effects are key considerations during this step. The evaluation may produce new groups based on even more specific classification. During the next stage, the manager must determine which lands require a fire management strategy that depends on considerations other than physical and biological characteristics and the fire situation. Included in this category are areas of ecological, archeological, geological, and other features of scientific, scenic, or historical value. Other considerations are grazing allotment, mineral lease, wildlife habitat, and private property. Special fire management zones can be created to reflect the special fire management needs of such land

The final outcome of this process will be a number of fire management zones, each requiring a unique fire management strategy to accomplish stated fire management objectives for the planning area. Each of these zones should be described and their boundaries mapped. Managers should clearly state fire management objectives and the desired response to fire for each zone.

The number of fire management zones described for a planning area depends on the number of different responses to fire desired and whether or not these

esponses are absolute or conditional. In other words, is he desired response required at all times under all burnng conditions or does it vary by time of year, weather onditions, or other variables?

Fire management zones usually reflect four primary esponses to fire: (1) fire suppression, (2) observation, 3) scheduled prescribed fire, and (4) conditional fire nanagement. Almost every existing wilderness fire nanagement plan, for example, has areas where any fire ıt any time is undesirable. Such areas can be described ıs being in **automatic fire suppression zones** or **fire ex-lusion zones**. Other areas where fire is considered ındesirable, but where damage potential varies with site ır burning conditions, might be designated as falling in-o **delayed attack zones**. Fires occurring in such areas nay not always need immediate attack. Still other areas vhere fire is generally unwanted may be designated as **nodified attack zones** in order to prohibit fire suppres-ion techniques deemed unacceptable because of adverse nvironmental impact. A primary response to fire, total uppression in this example, results in the designation of hree fire management zones. Another primary fire esponse is to allow all fires to burn as unscheduled rescribed fires regardless of time of year, burning con-litions, or other variables. Areas for which such a trategy is appropriate can be designated as **observation ones**. Areas designated for treatment with scheduled rescribed fires might be included in a single **scheduled rescribed fire zone**.

In many wilderness fire management planning areas, nost lands will fall into one or more **conditional fire nanagement zones** designed to allow a conditional response to fire, depending on time of year, elevation, burning conditions, and other variables. Such zones are labeled in a variety of ways, depending on external features, vegetation, use considerations, and other factors that best indicate the basis for creating the fire management zone.

The designation of fire management zones and the assignment of lands to fire management zones is interrelated with the development of fire management prescriptions for the zones. This is another case where planning steps are not clear cut. One distinction that can be made between these two tasks is that fire management zones are delineated by the kind of fire desired or expected; fire prescriptions are based on conditions likely to result from the desired or expected fire.

There is an important relationship between fire management zones and fire management units. A properly designated fire management unit imposes an area constraint to fires that may burn within the unit's boundaries.

Each fire management unit and zone should be delineated on a map of the fire management area. A brief written description of each unit and zone should include information about important fire-ecosystem interactions, special resource and use considerations, and relevant fire management objectives.

Teton Wilderness Example

The relationship between fire management unit and fire management zone is reflected in figure 5. This example is from the Teton Wilderness fire management plan

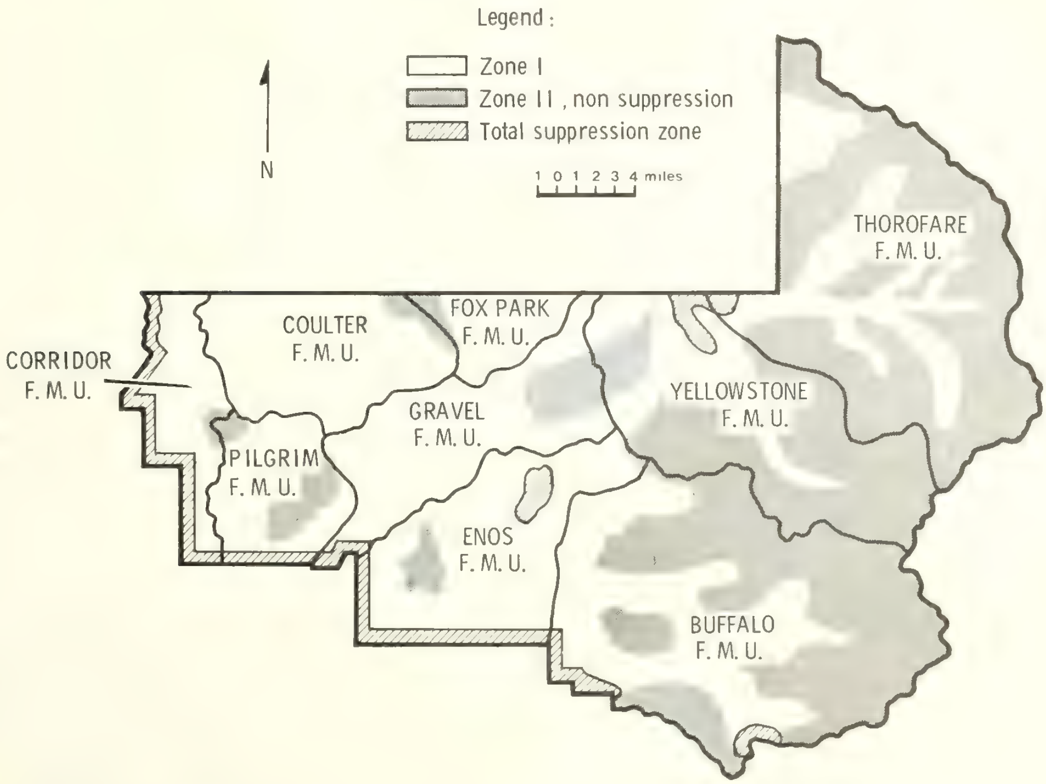

Figure 5.—Fire management units and zones, Teton Wilderness, Bridger-Teton National Forest, Wyo. (source: Reese and others 1975).

(Reese and others 1975). The fire management units are areas with recognizable and defensible boundaries, mostly drainage divides. The fire management zones reflect fire management objectives.

Cabinet Wilderness Example

A slightly different approach is shown by figure 6. This example is from the Cabinet Wilderness fire management plan (Schulte and Davis 1980). Two broad fire management zones have been established in the Cabinet Wilderness. These are described below:

1. The high elevation fire management zone[4] covers most of the wilderness. It is characterized by scree habitat types, shrub fields, and stands of scattered trees or clumps of trees in the subalpine zone. While the northwest portion of this area has some dense timber stands, there are no extensive tracts of continuous trees or fuels. Natural landforms, such as slides and rock outcroppings, will act as barriers to fire spread.

2. The remainder of the wilderness has been divided into four fire management units (see footnote 4). They are the Cedar Creek, Granite Creek, East Fork, and Flower Creek fire management units. These units deserve special considerations because of heavy, continuous fuels and dense forest cover.

Also, these units receive considerable use by visitors due to ready access by trails. In addition, the Flower Creek drainage is the municipal watershed for the town of Libby, Mont.

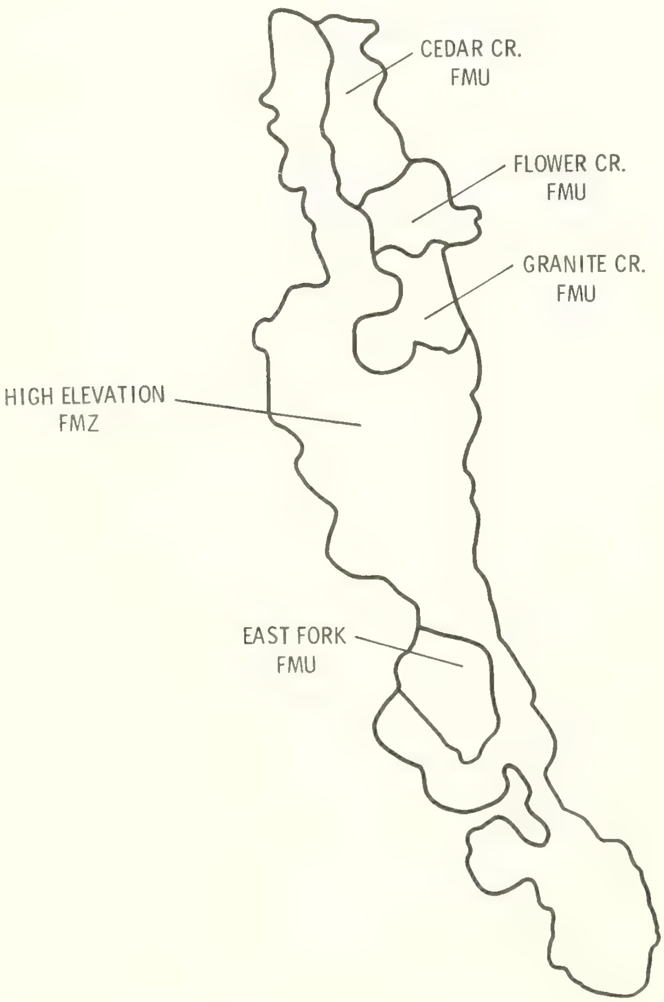

Figure 6.—Fire management units and zones, Cabinet Wilderness, Kootenai National Forest, Mont. (source: Schulte and Davis 1980).

Everglades National Park Example

The terrestrial mainland portion of Everglades National Park is divided into three fire management units, with three subunits (fig. 7). Delineation is based primarily on vegetation and fire ecology.

Fire Management Prescriptions

A fire management prescription is a written direction for dealing with the threat, occurrence, and use of fire within a fire management area, unit, or zone to accomplish land management objectives. Note that the scope of a fire management prescription is broader than that of a fire prescription. A fire prescription is a written direction for the use of fire. Traditional fire prescriptions are usually limited in scope. They primarily deal with the conditions under which a fire will be ignited, ignition techniques, and other factors directly related to the conduct of a burn. A fire management prescription must include necessary direction for the detection, prevention, and suppression of fires as well as for the use of fire.

Fire management prescriptions are usually written for a fire management unit or zone. Sometimes a single prescription will apply to several units with similar characteristics and fire management objectives. A single fire management prescription could conceivably apply to an entire wilderness fire management area, but such a situation is rare. The fire management prescription represents the culmination of fire management planning. Fire and ecosystem interactions, special resource and use considerations, and fire management objectives become manifest in the fire management prescription for a fire management unit or zone. The fire management plan, the final planning element, is a direct result of the fire management prescription(s). The plan tells how fire management prescriptions will be implemented.

The fire management prescription establishes standards upon which fire management decisions may be based. Criteria should be established for all fire management activities necessary to accomplish fire management objectives for the area of land covered by the prescription.

[4]Terminology has been changed to conform with usage in this guide. Both the zones and units described above are called "areas" in the Cabinet Wilderness fire management plan.

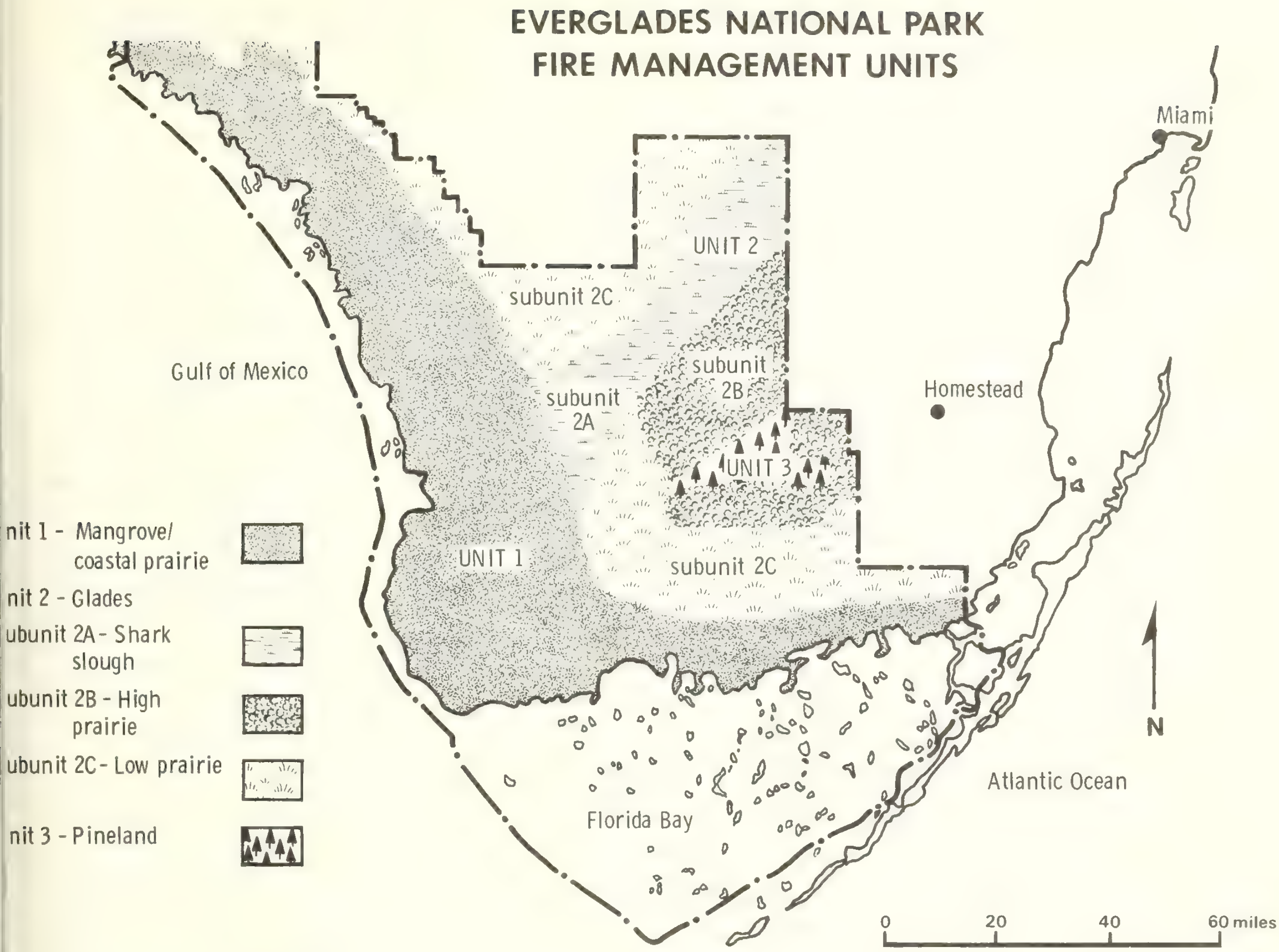

Figure 7.—Everglades National Park, Fla., fire management units (source: Koepp and Taylor 1979).

PRESCRIPTION DEVELOPMENT

It is difficult to suggest a step-by-step method for developing fire management prescriptions. Prescriptions that satisfy a given management objective in one planning area may fail to satisfy the same objective in another. No methodology can substitute for an intimate knowledge of the planning area, clear and concise management objectives, and a journeyman's knowledge of fire suppression, fire behavior, and fire effects. The following approach requires all four of these capabilities.

Partitioning the planning area into fire management zones and units can be an important first step in prescription development because such zoning reduces the often varied landscape to a manageable number of ecological land units and special areas for which prescriptions must be written. Preliminary prescriptions can be developed for each zone based on the fire response desired in each zone. After preliminary prescriptions have been developed, each zone can be evaluated on a fire management unit basis. The lands within a given management unit may fall into a number of fire management zones; within each unit, prescriptions for neighboring zones must be compatible. To illustrate this point, consider a special fire management zone with a prescription that requires total fire suppression and an adjoining downslope zone where the prescription calls for allowing certain fires to burn as unscheduled prescribed fires. Unless there is a natural barrier to fire along their common boundary, these prescriptions could be incompatible. Fire suppression might often be required to keep fire from entering the total suppression zone. This is not cost-effective fire management. As a general rule, prescriptions for adjoining zones should consider the natural fire spread tendency of a free-burning fire given the topography of the management unit. To deal with such situations, fire management zone designations must often be adjusted or preliminary zone prescriptions altered to reflect actual on-the-ground situations within a given fire management unit. It is unrealistic to expect all prescribed fires to remain in prescription unless the prescription is broad enough to allow a fire to encompass all the flammable area in its natural path. It is also unrealistic to depend on control action as a regular means of containing fires within a designated area.

Minimal control or holding action along a well-defined natural barrier to fire spread is the only practical approach to using unscheduled prescribed fire for attaining wilderness management objectives.

Another reason to prescribe fire management on a unit-by-unit basis is that fire management activities such as detection, prevention, and presuppression are best prescribed for a homogeneous unit of land that is easily identifiable on the ground.

Suggested procedures for developing prescriptions for scheduled prescribed fires are generally available (Mobley and others 1973; Martin and Dell 1978; Fischer 1978). Such prescriptions should contain directions for responding to unscheduled fire that might occur in areas where prescribed fires are scheduled.

PRESCRIPTION CRITERIA

As indicated earlier, fire management zones are based on the planner's interpretation of acceptable and unacceptable fires with respect to management objectives. To develop fire management prescriptions, the planner must also consider the conditions under which these acceptable and unacceptable fires are likely to occur. A fire management zone may be described, for example, as a zone in which preseason and postseason surface fires of low severity will be allowed to burn. To write a prescription for this zone, criteria must be established for preseason and postseason fires, for low severity fire, and for surface fire. These criteria must be measurable and must be immediately determinable at the time a fire is discovered. Examples of commonly used prescription criteria are elevation, calendar date, and fire danger rating indexes.

Selecting prescription criteria requires knowledge of the relationship between prescription variables and fire behavior. Some useful guides for this purpose are provided by Deeming and others (1977) and Albini (1976). A useful source of information is local records of fire occurrence and fire danger.

CONSTRAINTS

Fire management prescriptions are not complete until all constraints not previously considered are identified, defined, and incorporated into the prescription. Common constraints that often apply to wilderness fire management prescriptions have to do with:

Man-caused fires.—Agency policy often prohibits the use of accidental man-caused fires to accomplish management objectives.

Scheduled prescribed fires.—Agency policy may prohibit or restrict scheduled prescribed fires in wilderness.

Level of fire activity.—Prescribed fire programs are often shut down during periods of high fire activity.

Crew availability.—Use of unscheduled ignitions to accomplish management objectives is often tied to the availability of fire crews to handle possible escapes.

Suppression methods.—A complete ban on certain fire suppression methods and use of certain firefighting equipment is often imposed in wilderness.

Air quality guides.—Smoke management plans often restrict or prohibit prescribed fires during periods of poor ventilation.

Life and property.—Visitor safety and private property must always be protected.

Additional constraints may exist, depending on the particular situation. It is important to recognize all constraints during planning so that they can be reflected in fire management prescriptions.

ORGANIZATION AND CONTENT

The organization and content of fire management prescriptions should reflect the fire management situation on the planning area. Some prescriptions can be quite simple because the fire management activities planned for the area are quite simple. Other prescriptions will be complex. The following suggested outline should handle most situations. Each item (A-C) should be repeated for each management unit.

SUGGESTED OUTLINE FOR FIRE MANAGEMENT PRESCRIPTION

I. Fire Management Unit (name or number)
   - A. **Fire detection**. If special detection needs are indicated, enumerate them and describe criteria for initiating action. If planning area detection is covered in some other fire management plan, cite the plan and summarize pertinent information.
   - B. **Fire prevention**. Indicate all special fire prevention actions planned for the unit. Describe criteria for initiating action. If planning area prevention actions are covered in some other fire management plan, cite the plan and summarize pertinent information.
   - C. **Presuppression**.
     1. **Preattack**. If the area is covered by a preattack plan, cite the plan and summarize pertinent information. If preattack plan does not exist, preattack procedures should be developed as part of the planning process and described here Preattack procedures will depend on the fire potential and constraints imposed by fire prescriptions (Aldrich and Mutch 1973). USDA Forest Service preattack planning guides are available for many parts of the United States (for example, USDA Forest Service 1978b; Dell 1972).
     2. **Fuel management**. Planned fuel management actions should be enumerated. In many wildernesses fuel management is limited to slash disposal in conjunction with trail construction and maintenance. Fuel treatment on outside lands along wilderness boundaries may be appropriate in some cases.

3. **Fire prescriptions**. Details on the planned response to a fire occurrence should be described separately for each fire management zone.
   For each fire management zone describe:
   a. Conditions when fires will be aggressively attacked and suppressed,
   b. Conditions when fires will be suppressed, but attack will be less than aggressive,
   c. Constraints on fire attack and suppression,
   d. Conditions when unscheduled fires will be allowed to burn as prescribed fires,
   e. Constraints on allowing unscheduled fires to burn as prescribed fires, and
   f. If prescribed fires are scheduled in the fire management zone, fire prescriptions for each planned fire.

Alternative prescriptions for unscheduled prescribed fires can be evaluated with the aid of a computer system designed by Bevins and Fischer (1983a,b). The technique uses historical fire occurrence and weather records to identify ignitions that would meet manager-specified criteria for prescribed fires. Qualifying fires are "allowed to burn" under prevailing weather conditions until extinguished by precipitation or until prescribed conditions are exceeded.

Fire Management Plan

Fire management prescriptions tell how to achieve fire management objectives for the planning area. The fire management plan tells who will do what and when and where the fire management objectives will be accomplished.

DECISION SCHEME

A major part of the fire management plan is a decision scheme for implementing the fire management prescriptions for the planning area. The decision scheme assures that all prescription criteria and constraints are systematically considered before a response to a fire is selected. It should allow the fire manager to quickly determine if a fire is a wildfire or an unscheduled fire as defined by the fire prescription. The scheme should also indicate, again according to the prescription, what type of attack and suppression methods are appropriate if wildfire is indicated. This same decision scheme, if properly constructed, is used to help determine if a prescribed fire continues to burn within prescription on a daily basis (fig. 8).

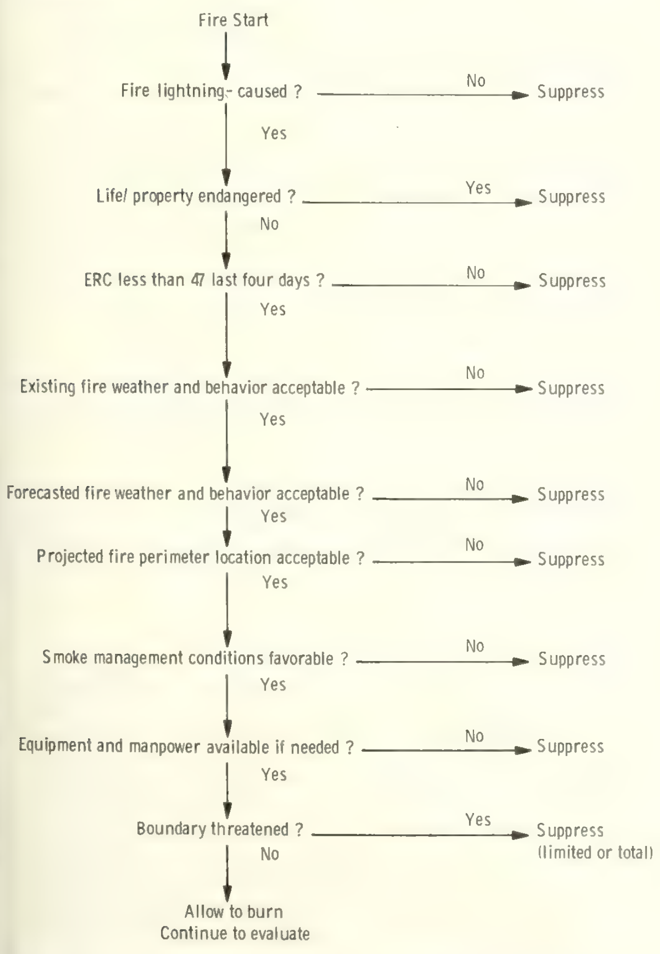

Figure 8a.—Decision flow chart for evaluating fires occurring in high elevation fire management zone against prescription criteria, Cabinet Wilderness (see fig. 6), Kootenai National Forest, Mont. (source: Schulte and Davis 1980).

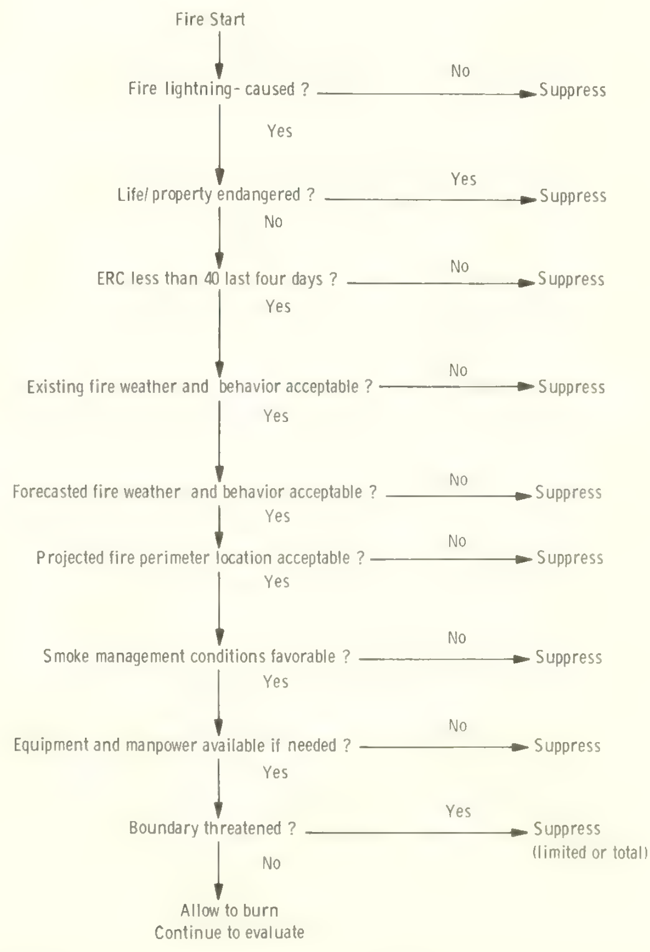

Figure 8b.—Decision flow chart for evaluating fires occurring in Cedar Creek, Granite Creek, and East Fork fire management units against prescription criteria, Cabinet Wilderness (see fig. 6), Kootenai National Forest, Mont. (source: Schulte and Davis 1980).

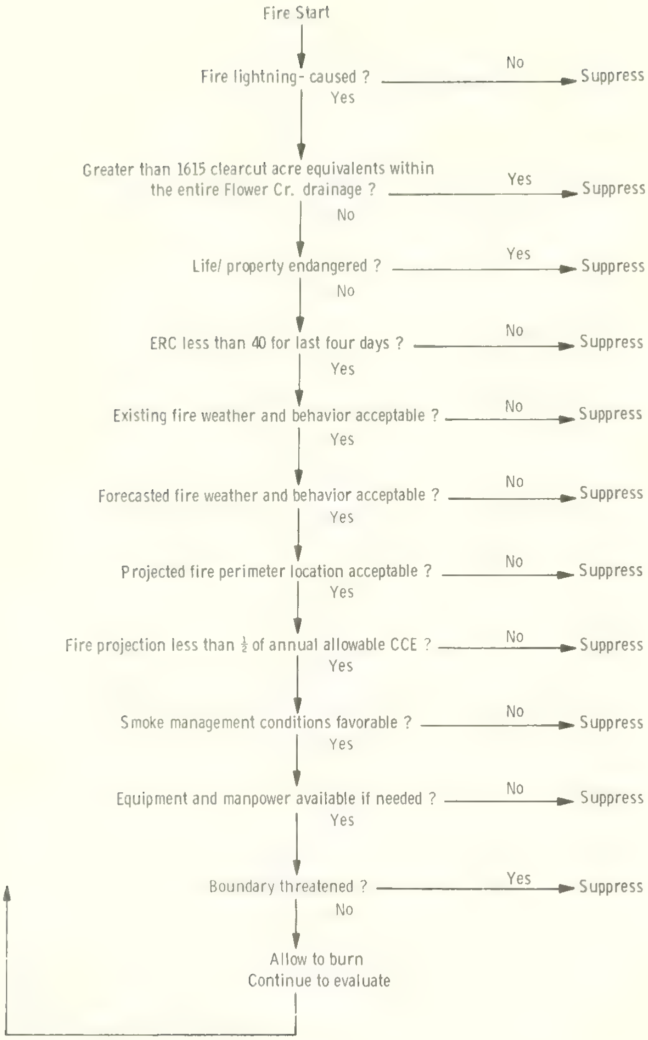

Figure 8c.—Decision flow chart for evaluating fires occurring in Flower Creek fire management unit against prescription criteria, Cabinet Wilderness (see fig. 6), Kootenai National Forest, Mont. (source: Schulte and Davis 1980).

ASSIGNMENT OF RESPONSIBILITY

The plan should identify who is responsible for determining appropriate action regarding fire. Fire management prescriptions and associated decision schemes are guides for decisionmaking. Decisions regarding fire should rarely, if ever, be automatic. Current technology for predicting fire behavior and associated fire effects is imperfect, and the probability of unanticipated burning conditions is great. Decisions must be based on what a fire is actually doing and what it is likely to do, not on some prefire prediction of what it is supposed to do. Fire management decision systems should, consequently, always include diagnosis by experienced fire and resource specialists. The plan should require such diagnosis and specify the level of expertise required of such decisionmakers (fig. 9).

FIRE MONITORING

Assignments and procedures for collecting and reporting the information required to evaluate fire starts in terms of prescription criteria are a part of the plan. Procedures for fire monitoring and qualifications of fire monitors should be included unless established standards apply. **Fire monitoring is the act of observing a fire to obtain information on its environment, behavior, and effects for the purpose of evaluating both the fire and its prescription.** Fire monitoring provides the information needed to make daily decisions regarding prescribed fires. Fire monitoring also supplies information needed to cope with agency requirements for documenting fire management actions. Information gathered by qualified fire monitors can be used to verify or adjust fire prescriptions. The National Wildfire Coordinating Group has published an excellent guide to assist in the operational monitoring and evaluation of prescribed fires (Van Wagtendonk and others 1982).

SCHEDULED PRESCRIBED FIRES

A schedule of all manager-conducted prescribed fires planned for the wilderness is an important part of the plan. Burning plans for these fires should also be included (for example, see Mobley and others 1973; Martin and Dell 1978; Fischer 1978). A separate decision scheme for identifying prescribed conditions for scheduled fires may be desirable.

EVALUATION OF FIRE EFFECTS

The actual effect of a prescribed fire or a wildfire in terms of wilderness fire management objectives is the ultimate test of the fire management prescription. The plan should contain a fire effects evaluation procedure and a procedure to use results of such evaluations to make necessary adjustments of prescriptions. Some examples of wilderness fire evaluations are provided by Collins (1980), Garcia and others (1979), Gochnour and Bailey (1980), Keown (1980), Racine (1979), and USDA Forest Service (1979).

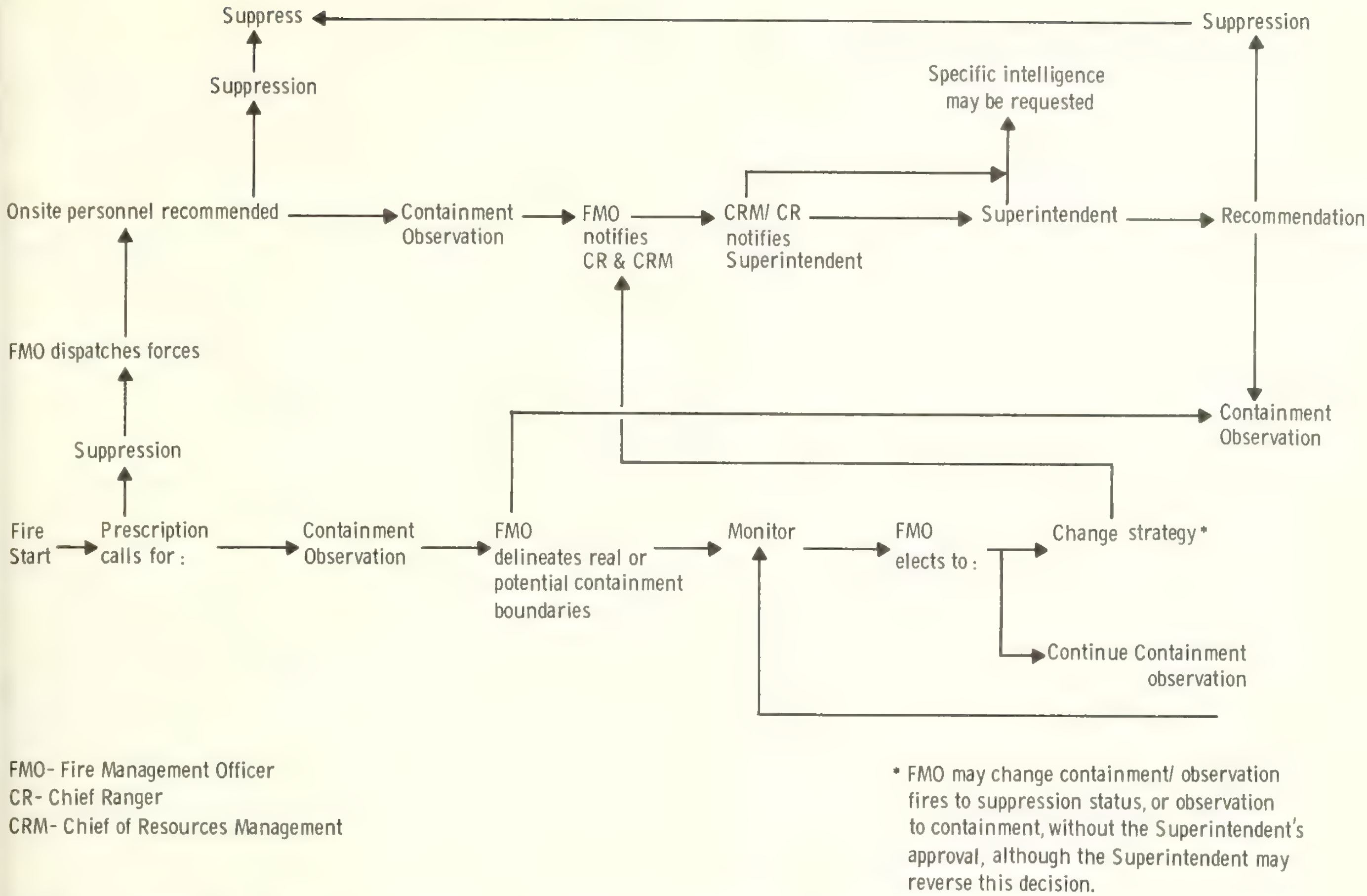

Figure 9.—Flow chart indicating responsibility for making fire management decisions, Sequoia and Kings Canyon National Parks, Calif. (source: Bancroft and Partin 1979).

FIRE PREVENTION

Most wilderness fire management prescriptions require suppression of all unauthorized man-caused ignitions. Fire prevention is, therefore, an important wilderness fire management activity. It is better to prevent unwanted fires than to sustain unacceptable loss to the wilderness resource as a result of fire or fire suppression activities. Include wilderness fire prevention activities in the plan.

FIRE PRESUPPRESSION

The manager should identify and describe presuppression activities relevant to the fire management prescription in the plan. Items such as detection, preattack plans, preparedness requirements, mobilization of forces, dispatching procedures, and collection of data for fire danger rating should be included. Include only those items relevant to implementing the fire management program for the wilderness area. If separate presuppression plans apply to wilderness lands the plan should be identified and applicable sections briefly summarized in the fire management plan.

FIRE SUPPRESSION

The plan should indicate fire suppression standards and constraints not included elsewhere and procedures for determining actions when fires escape.

VISITOR SAFETY

The plan should specify all special actions necessary to assure visitor safety when fires are burning in the wilderness area. Examples are information programs at wilderness entrances, signing, trail closures, personal contact of visitors near fires, and evacuation procedures in case an emergency situation develops.

SMOKE MANAGEMENT

Smoke management considerations governing the conduct of the fire management program should be described in the plan. Actions necessary to comply with rules, regulations, and other requirements for maintaining air quality should be identified.

PUBLIC INFORMATION AND INVOLVEMENT

The planned use of fire to accomplish wilderness management objectives is new. Few wilderness fire management prescriptions have been tested over a range of fire conditions. The support of resource managers and the general public is necessary to develop wilderness fire management effectiveness. Wilderness fire management plans should, therefore, outline a program of public involvement and information regarding planned fire management activities in the wilderness. This program should include participation by the Agency, as well as by cooperating Federal and State agencies.

Newlon (1981) identified two major aspects to public involvement in fire management: (1) doing a good technical job of managing fires and (2) telling the public about the good job you are doing. He suggests the following basic steps be considered when planning a public involvement program:

1. Define the issues in legal, ecological, social, and economic terms.
2. Communicate in layman's English, or in other languages—Spanish, French—as appropriate.
3. Make public involvement an integral part of any plan, program, or project and not a separate procedure.
4. Provide full and timely information about upcoming fire management decisions, and offer many opportunities for the public to be involved in the decisionmaking process.
5. Identify the publics affected by the program or project and help them participate in the planning process.
6. Collect comments from the public, analyze them, and respond to recommendations.
7. Document all public participation; describe how the public's input was used in the decisionmaking processes.

The skills needed, steps to be considered, and techniques to carry out effective public participation programs are thoroughly discussed in the USDA Forest Service Public Participation Handbook, Parts I and II (USDA Forest Service 1980).

NOTIFICATION AND REPORTING

Requirements for notifying designated agency and cooperator agency officials and filing necessary in-service reports of wilderness fire management activities should be spelled out in the plan. Responsible individuals should be identified by name and position.

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APPENDIX A: PARK AND WILDERNESS FIRE MANAGEMENT PROGRAMS, 1972-81

Table A-1.—Prescribed fire programs in National Parks and Monuments (adapted from Sellers 1982) (source: Kilgore 1983)

Parks and monuments by region	Size	Natural fire zone	Years covered	Prescribed fire: Lightning ignitions		Prescribed fire: Human ignitions	
	---------*Acres*---------			*No.*	*Acres*	*No.*	*Acres*
Pacific Northwest							
Crater Lake	160,290	110,000	1976-1980	6	542	2	4,225
North Cascades	504,785	430,000	1976-1980	52	1,471	—	—
Western							
Grand Canyon[1]	1,226,656	1,077,000	1971-1981	33	3,527	12	2,771
Chiricahua	11,440	2,000	1979-1981	—	—	7	46
Hawaii Volcanoes	229,117	96,000	1977-1981	2	698	7	1,108
Lassen Volcanic	106,372	106,000	1979	2	4	—	—
Lava Beds	46,821	—	1974-1981	—	—	30	3,105
Pinnacles	16,215	—	1974-1981	102	1,265		
Point Reyes	68,000	—	1979-1981	—	—	27	1,418
Redwoods	160,000	—	1980-1981	—	—	10	72
Saguaro	83,576	56,000	1971-1981	51	927	—	—
Sequoia-Kings Canyon	862,429	740,000	1968-1981	208	21,982	93	21,412
Whiskeytown	43,500	—	1980-1981	—	—	7	66
Yosemite	761,094	656,000	1970-1981	239	17,525	56	18,364
Santa Monica	6,000	—	1981	—	—	1	30
Southwest							
Big Bend	708,221	533,000	1980-1981	2	680	—	—
Carlsbad-Guadalupe	46,755	—	1979-1981	—	—	2	4
Bandelier	36,971	12,000	1980-1981	6	75	—	—
Rocky Mountain							
Dinosaur	211,050	206,000	1980-1981	3	—	1	60
Glacier	1,013,594	100,000	1980-1981	—	—	1	5
Grand Teton	310,418	145,000	1972-1981	23	5,553	1	35
RockyMountain[2]	263,793	—	1973-1978	17	1,051	—	—
Wind Cave	28,060	—	1973-1981	—	—	24	3,299
Yellowstone	2,221,772	1,700,000	1972-1981	114	33,169	—	—
Devil's Tower	1,350	—	1974-1975	—	—	3	51
Midwest							
Isle Royale	571,976	132,000	1976-1980	1	5	—	—
Homestead	163	—	1970	—	—	1	90
Fort Larned	718	—	1968-1975	—	—	56	450
Herbert Hoover	186	—	1972	—	—	1	76
Pipestone	282	—	1976-1980	—	—	66	859
Southwest							
Big Cypress	570,000	—	1978-1981	—	—	44	13,225
Everglades	1,400,533	705,000	1951-1981	160	46,758	281	112,661
Mid-Atlantic							
Shenandoah	194,078	—	1975-1981	—	—	10	159
North Atlantic							
Cape Cod	44,600	—	1977	—	—	1	40
TOTAL		6,794,000		919	133,967	846	183,674

[1]Natural prescribed fire program at Grand Canyon began in 1978.
[2]Rocky Mountain's program suspended in 1978 after Ouzel Fire had to be suppressed.

Table A-2.—Natural fire programs in National Forest wilderness, 1972-81 (source: Kilgore 1983)

Area	Plan approved	Acres			Fires allowed to burn	Acres within fire perimeter
		Wilderness	nonwilderness	Total		
REGION 1						
Anaconda-Pintler Wilderness	1978/79		159,086	2	125	
Beaverhead NF		72,383				
Bitterroot NF		41,344				
Deerlodge NF		45,359				
Selway-Bitterroot Wilderness				1,134,086		
Clearwater NF	1979	265,779			76	38,855
Bitterroot NF	1972/78	308,795				
Nezperce NF	1974/78	559,512				
High Elevation Bitterroot FMA	1978	68,960	8,840	77,800		
Bitterroot NF						
Camp Tolan FMA	1978		39,848	39,848		
Bitterroot NF						
Troy Ranger District FMA	1979		309,272	309,272	1	542
Cabinet Mountains Wilderness	1980	94,272		94,272		
Kootenai NF						
Scapegoat Wilderness and Danaher Unit, Bob Marshall Wilderness	1981			433,900	2	232
Flathead NF		166,200				
Helena NF		80,700	6,300			
Lewis and Clark NF		80,600	19,200			
Lolo NF		74,800	6,100			
Upper Rock Creek FMA	1982		175,699	175,699		
Deerlodge NF						
Absaroka-Beartooth Wilderness	1982	921,574		921,574		
Gallatin NF and Custer NF						
			REGION 1 TOTALS	*3,343,325*	*81*	*39,754*
REGION 2						
Dolores FMA	1978		498,000	498,000	38	31
Mancos FMA	1978		187,000	187,000	6	2
San Juan NF						
Washakie Wilderness	1978	687,132		687,132	3	26
Shoshone NF						
North Absaroka Wilderness	1979	351,104		351,104	0	0
Shoshone NF						
Flat Tops Wilderness	1979	235,230		235,230	0	0
White River NF						
			REGION 2 TOTALS	*1,958,466*	*47*	*59*

(con.)

Table A-2.—(con.)

Area	Plan approved	Acres			Fires allowed to burn	Acres within fire perimeter
		Wilderness	nonwilderness	Total		
REGION 3						
Gila Wilderness	1975	162,990	8,830	171,820	95	10,903
Gila NF						
Blue Range Primitive Area	1979	169,000	24,000	193,000	24	7,100
Apache-Sitgreaves NF						
A/S other			22,400	22,400		
Galiuro FMA	1978	52,717	85,529	138,246	1	50
PuschFMA	1982	56,430		56,430		
Rincon FMA	1978		73,600	73,600		
Coronado NF						
San Pedro FMA	1978					
Santa Fe NF		41,132		41,132	4	—
Natural fire areas	1979					
Coconino NF			319,100	319,100	45	8
Natural fire areas	1980					
Tonto NF		105,569	26,206	131,775		
			REGION 3 TOTALS	*1,147,503*	*169*	*18,061*
REGION 4						
Teton Wilderness						
Bridger-Teton NF	1976/82	585,000		585,000	49	209
Sawtooth Wilderness						
Sawtooth NF	1982	248,518		248,518	12	46
Lake Fork FMA	1979/81		93,030	93,030	5	1,248
Payette NF						
Bee Hive Peak FMA	1982	275,260	275,260			
Fishlake NF						
High County FMA	1982		289,865	289,865		
Targhee NF						
West Slope FMA	1982		170,795	170,795		
Targhee NF						
Big Hole FMA	1982		150,000	150,000		
Targhee NF						
			REGION 4 TOTALS	*1,812,468*	*66*	*1,503*
REGION 5						
Caribou Wilderness						
Lassen NF	1982	19,080		19,080		
REGION 6						
Eagle Cap Wilderness						
Wallowa-Whitman NF	1982	293,735		293,735	6	3

APPENDIX B: SELECTED REFERENCES FOR PARK AND WILDERNESS FIRE MANAGEMENT PLANNING

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Fischer, William C. Wilderness fire management planning guide. General Technical Report INT-171. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1984. 56 p.

Outlines a procedure for fire management planning for parks; wilderness areas; and other wild, natural, or essentially undeveloped areas. Discusses background and philosophy of wilderness fire management, planning concepts, planning elements, and planning methods.

KEYWORDS: wilderness fire management, natural fire programs, wilderness, fire management, land management planning

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

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United States Department of Agriculture

Forest Service

Intermountain Forest and Range Experiment Station Ogden, UT 84401

General Technical Report INT-172

October 1984

Proceedings—Symposium on the Biology of *Atriplex* and Related Chenopods

Provo, Utah, May 2-6, 1983

FOREWORD

Members of the plant family Chenopodiaceae, or chenopods, are found in salt deserts throughout the world. They are represented by a variety of growth forms including low annual herbs, perennial herbs, halfshrubs, shrubs, and, rarely, small trees. Chenopods are a unique family of plants with many physiological, morphological, and genetic adaptations and characteristics that enable them to survive and even flourish in highly stressful conditions of moisture, salinity, soil pH, temperature, and animal use. They are most commonly found in waste places, saline areas, and in desert and semidesert environs.

There is growing recognition throughout the world, particularly in areas suffering from desertification, of the value of chenopod plants for revegetation of harsh, highly disturbed sites. There is also a mounting concern for adverse changes that are taking place in communities of chenopod plants as a consequence of management and development activities.

Through the past several decades, a substantial amount of research has been conducted in habitats where chenopods occur. Management programs have intensified to explore their utilization for revegetation, range livestock, fuelwood, and wildlife. However, to date, there has been little effort in western North America to bring this information to the individuals involved in research and management of chenopods.

This symposium is intended to provide scientists, educators, and wildland managers with the most advanced knowledge and technology to use and manage this diverse and unique plant family. These proceedings contain a wide spectrum of information including basic physiological functions, genetics and evolution, ecological relationships, animal relationships, and management procedures.

Approximately 120 to 150 participants from land management agencies, colleges, universities, and Federal research organizations attended the symposium and field trip.

Proceedings—Symposium on the Biology of *Atriplex* and Related Chenopods

Provo, Utah, May 2-6, 1983

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CONTENTS

INTRODUCTORY REMARKS

Douglas F. Day

I am pleased to join this esteemed group today. I welcome you to Utah to this symposium which is dedicated to a very important group of shrubs, the chenopods.

The large amount of interest in shrubs that this group is demonstrating is most gratifying. Habitat is the foundation of big game management in Utah. Shrubs occupy the major portion of our fall, winter, and spring ranges and all of our desert big game ranges.

It is meetings like this, and the work that precedes and follows them, that make my job as an administrator easier and much more fulfilling.

Twenty-eight years ago a joint big game winter range improvement research project between the Intermountain Forest and Range Experiment Station and the Utah Division of Wildlife Resources (then, Fish and Game) was begun. This cooperative effort has proven to be one of the most productive range improvement projects in North America.

When the joint effort started, little was known regarding how to improve ranges for big game or even what constituted ideal game range. Our joint efforts have resulted in the development of techniques, procedures, equipment, and plant materials that are being used throughout North America and the world for improving big game and livestock ranges and for rehabilitation of disturbed lands.

Results of much of this work, a summary of a quarter century of research and experience, will soon be published. This book will include: (a) principles and procedures of range rehabilitation, (b) descriptions, characteristics, and potential use of over 400 plant taxa, (c) characteristics and uses of equipment and techniques in range rehabilitation, and (d) guides for seeding all major range types from the subalpine down to and including the blackbrush.

One of the major objectives of the Division is the acquisition and improvement of big game ranges. Why do we place so much importance on big game range improvement and habitat management? Big game are important to Utah and to its citizens. The esthetic value of big game is immeasurable. Big game provide a good percentage of Utah citizens with quality recreation. License revenues from big game permits provide over 45 percent of the Division's income. The number of people who receive recreation opportunities and the revenue derived from licenses for each species are:

Species	No. License Holders	Cost of Licenses
Mule deer	200,000	$5,000,000.00
Elk	23,000	800,000.00
Antelope	450	12,000.00
Moose	110	11,000.00
Buffalo	28	8,500.00
Desert Big Horn sheep	11	25,000.00
Rocky Mountain goat	1	200.00
	223,600	$5,856,700.00

An important benefit that has been derived from range improvement efforts has been enhanced watershed protection and improvement.

One of the most important results of our joint research has been gaining a firm appreciation of many plant taxa. We are meeting today to bring together those who are interested in *Atriplex* and related chenopods. There is more potential within the chenopod family for use in rehabilitation of disturbed lands in the West than in any other plant family. A majority of our desert deer and antelope ranges, along with the foothill winter ranges of central and northeastern Utah, are inhabited by or adapted to *Atriplex* and related chenopods.

It is most fitting that this group has assembled here this week to expand our knowledge and understanding of *Atriplex* and related chenopods.

Douglas F. Day is Director of the Utah Division of Wildlife Resources, Salt Lake City, Utah.

A TOUR OF CHENOPODS IN WESTERN UTAH

Howard C. Stutz

As a part of the symposium on "Atriplex and Related Chenopods", May 2-6, 1983, a 2-day field trip was conducted in western Utah. Nearly every major chenopod genus and most of the major chenopod species of western America were seen. To provide a review of the trip for the participants and an opportunity for a self-guided tour for others who may wish to become better acquainted with this remarkable group of plants, this short essay has been prepared, describing the major populations which were visited. Because of the muddy roads encountered on the tour a few sites which had been included in the original plan were not visited; however, descriptions of some of these are included to make the review that much more complete.

The field trip begins in Rush Valley, about 40 miles (64 km) west of Provo. To get there from Provo, it is best to go by way of Lehi, Cedar Fort, and Fairfield on Utah Highway 73. This cuts through Cedar Valley west of the Oquirrh Mountains. Until recently Cedar Valley contained mature native stands of sagebrush and greasewood but has now been turned mostly into agriculture.

Rush Valley begins at the Utah-Tooele County boundary. Almost the entire chenopod tour will be within Tooele County. Like most valleys of western Utah and Nevada, Rush Valley extends north and south with steep mountains on each side. The bottom lands are occupied almost exclusively by chenopods; the lower slopes have a mixture of chenopods and composites (notably Artemisia, Chrysothamnus, and Tetradymia); junipers and pinyon pine dominate the upper slopes.

Stop #1: Diploid Atriplex confertifolia

The first stop on the tour is about 1 mile (1.6 km) west of the Utah-Tooele County line. To get there, turn onto the road to Faust and proceed 0.5 mile (0.8 km) west. As for most of the tour stops, it is best to leave the car and walk out into the vegetation. As you walk out to the north of your car you will encounter several plant species which will be present throughout much of the tour. The most conspicuous shrubs are Artemisia tridentata Nutt. var. wyomingensis (Torr. & Frem.) Wats., Chrysothamnus viscidiflorus (Hook) Nutt. var. stenophyllus (Gray) H. M. Hall, and Atriplex confertifolia (Torr. & Frem.) Wats. The most common perennial grass is Oryzopsis hymenoides (R. & S.) Ricker (Indian ricegrass).

Atriplex confertifolia (shadscale) here is diploid (2N=18 chromosomes). Notice that the plants are widely spaced, vigorous, 15-30 inches (38-76 cm) tall, and very thorny. This is the general appearance of all diploid populations of shadscale. Polyploid populations, as you will see later, usually grow in dense, uniform, crowded populations in association with very few other species. Polyploid plants are also smaller in stature than diploids. Throughout the tour, the diploid form of shadscale will be routinely encountered on the upper valley slopes in association with sagebrush, rabbitbrush, and junipers as seen here. Populations of shadscale in the bottom lands are all polyploids (2N=36 or 2N=72 chromosomes).

Stop #2: Atriplex falcata, Ceratoides lanata, and Experimental Plantings

To get to Stop #2, continue westward on the Faust road for 1.5 miles (2.4 km) where there is a dirt road to the right (north). Follow this dirt road for 3.5 miles (5.6 km) where you will come to three USDA Forest Service fenced exclosures in which are planted several species of shrubs. Among them are some chenopods which might interest you.

As you approach the exclosures, stop and walk out toward the south side of the first (southernmost) exclosure. You are now in an almost pure stand of Atriplex falcata (Jones) Standl. It is one of the smallest statured of all perennial Atriplex and in midwinter or very early spring is often quite obscure. However, it begins its spring growth very early and is conspicuous and beautiful by early June. Fruits usually mature by late June or early July.

Plants in this population are diploid (2N=18). Some other populations are tetraploid (4N) with 36 chromosomes and some are hexaploid (6N) with 72 chromosomes, but most populations are diploid. A few miles from here is one of the hexaploid

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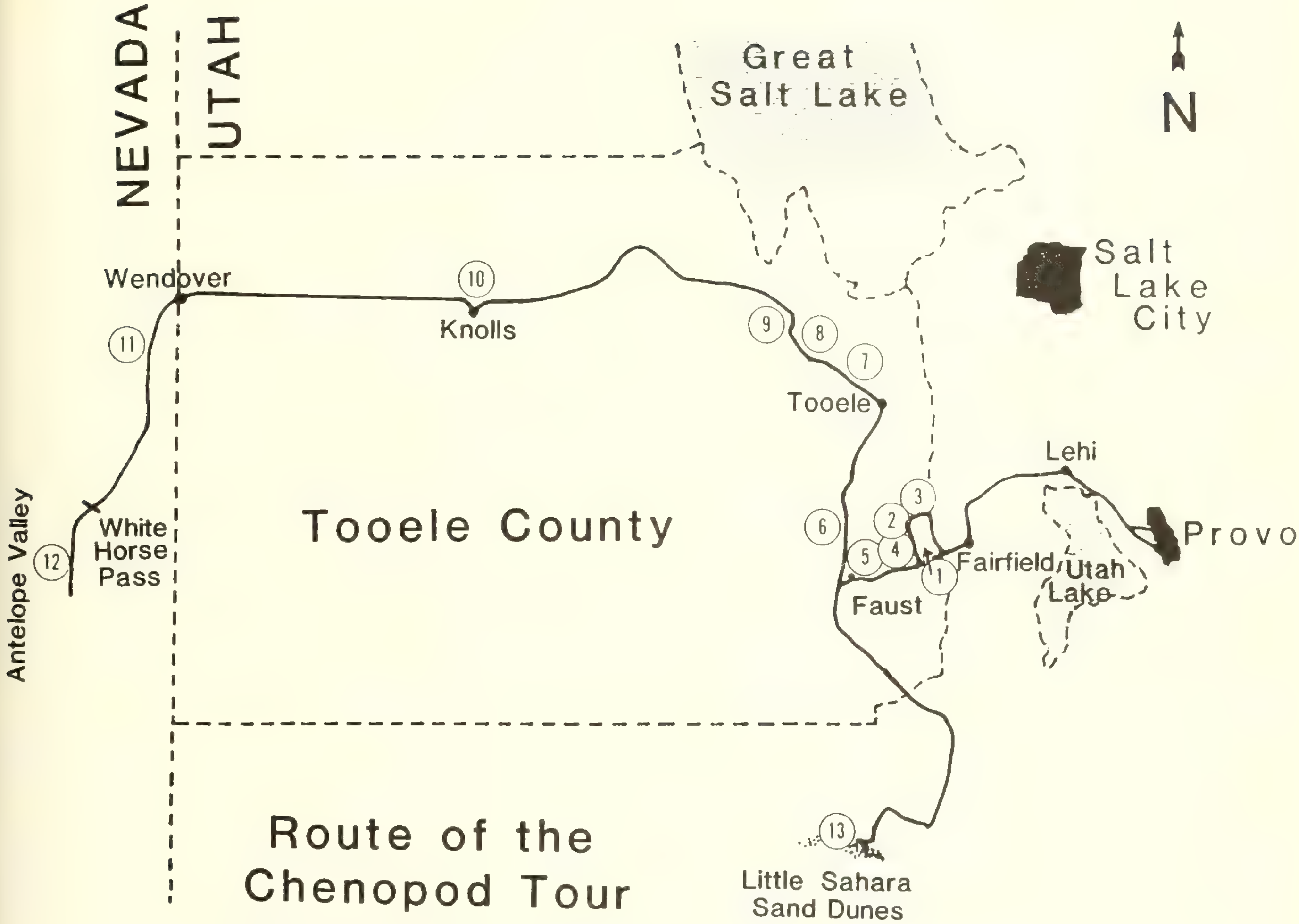
Howard C. Stutz is Professor, Department of Botany and Range Science, Brigham Young University, Provo, UT.

This paper is the result of an invited account of the field tour of May 3 and 4 especially modified for "do it yourself" visits.



Route of the Chenopod Tour

Showing the location of the major stops

(6N) falcata populations which we will visit later on today. Diploids occur in dense patches like this throughout southern Oregon, southern Idaho, northern Nevada, and most of Utah. They look quite different from population to population, but all have in common the early flowering habit, a pronounced taproot system, tiny linear leaves, and small-beaked fruits. It is thought that A. falcata was derived from a more northern highly variable species (the proposed name for it is A. "canadensis"[1] but is not yet published). A. "canadensis" appears to be ancestral also to A. gardneri (Moq.) D. Dietr. and to A. tridentata Kuntze. A. gardneri is found only in more northern latitudes (Montana, Wyoming, North and South Dakota) so will not be encountered today but, A. tridentata is abundant in Utah and Nevada and will be present in most of the valley bottoms throughout the tour.

Because Atriplex falcata usually grows on high-quality silty-loam soils, much of it has already been destroyed by the recent spread of agriculture and by the widespread introduction of crested wheatgrass. It is also highly palatable and highly nutritious which, in association with its early spring flush of growth, has made it a much preferred species for early spring grazing. This appears to have also taken a large toll.

Another prized chenopod, which has taken abuse for the same reasons, is abundant immediately to the north of where you are standing. All of that beautiful light-gray vegetation is Ceratoides lanata (Pursh) J.T. Howell (winterfat). It too is palatable, nutritious, grows on some of the best soils, and, being evergreen, is preferentially sought out for winter and early spring grazing, apparently much to its detriment.

Ceratoides lanata is almost always diploid (2N=18). But it doesn't want for genetic variation by other means. It has apparently accumulated numerous mutations. It shows variation in many characteristics but is particularly strikingly variable in its stature. Some populations consist of plants that grow to 20 to 30 inches (50 to 75 cm); in other populations plants seldom exceed 4 inches (10 cm). The stature of the plants in the population in which you are now standing is quite typical for most populations throughout western Utah. But throughout its wide range from Alaska to Mexico, many ecotypes have evolved. It should be very easy to select strains which would be superiorally adapted for use on particular sites.

[1] In this article I have used several tentative species names which have not yet been formally published. These are A. "canadensis", A. "dollyvardensis," A. "robusta," and A. "tooelensis." One tentative subspecies is A. canescens (Pursh) Nutt. var. "gigantea."

Stop #3: Grayia spinosa (Spiny Hopsage)

There is a small population of Grayia spinosa (Hook.) Moq. about 1 mile (1.6 km) east of here. To get to it, drive about 0.10 of a mile (.16 km) north and then turn east on a winding dirt road. This road will lead back to the asphalt, but about halfway there it traverses a nice population of G. spinosa. As you drive, notice the extensive populations of Ceratoides. They appear as rivers flowing down the gentle slopes, alternating at times with A. falcata, sometimes with cheatgrass (Bromus tectorum L.) and sometimes, particularly farther up on the slopes, with sagebrush.

Notice also as you drive toward the Grayia population that you go through some populations of large Artemisia tridentata var. tridentata. These are usually diploid, whereas the shorter statured A. tridentata var. wyomingensis is usually tetraploid.

The appearance of Grayia spinosa varies from season to season, but it is usually strikingly different from all of its associates, so there is usually no difficulty in picking it out. Its bark is quite distinctly gray-purple. In winter and spring the buds look like tiny white cabbages scattered alternately along the thorn-tipped branches. When in leaf, the broad succulent leaves are very distinctive, and when in fruit (in early summer) the large variously colored bracts give a spectacular show which attracts one's attention even when far off.

Grayia spinosa is an evolutionary puzzle. There are no clues to its ancestry. It stands alone in almost every attribute from all other chenopods. It is nutritious and palatable, but its thorns usually keep it from being utilized. It usually grows in soils less alkaline and less salty than those tolerated by other chenopods. It sometimes grows in extensive populations but is also commonly found in small clusters like this somewhat isolated population.

Another mile (1.6 km) up the road (going east) you come again to Highway 73 (asphalt). If you were to follow it to the north it would bring you to Tooele. But instead, turn south and go back once again to the Faust exit (about 4 miles, 6.4 km) where you will once again turn to the west and go down into the valley bottoms. Notice as you travel back to the Faust exit that the highway traverses a rich mixture of sagebrush, rabbitbrush and diploid shadscale, similar to that at the first stop.

Stop #4: Kochia americana and Sarcobatus vermiculatus

At the Faust exit, make a sharp turn to the right (west) and proceed for 2.5 miles (4 km) to a nice population of the chenopod Kochia americana Wats. It is best developed on the north side of the road opposite a conspicuous clay mound.

Kochia americana is the only perennial species of Kochia in America and is remarkably unknown. Few plant species enjoy such anonymity. Essentially nothing is known of its genetics, evolution, physiology, or ecology. This is the most extensive population that I know of, but it is common as a minor component on many of the chenopod-occupied lands of western North America. Usually, a few plants will be found here and there on the harshest sites.

Being deciduous and of small stature, K. americana is utilized very little by herbivores. It has bisexual flowers and because of its apparent uniformity, is probably sexually self-compatible.

On the south side of the road, around the clay mound and extending far up into the valley, is a large population of Sarcobatus vermiculatus (Hook.) Torr. (greasewood). Because of its large stature (3 to 8 feet, 1 to 3 m) and extensive stands, S. vermiculatus is one of the most conspicuous of all chenopods. It is most commonly found in sites such as this where salinity and ground water are both high. In some places it becomes abundant on valley slopes and on small sand dunes, but even in those situations the deep extensive root system is probably in water.

Throughout the remainder of the tour, greasewood will be encountered many times. In some places it is very heavily grazed. Some stands have been burned and some railed in attempts to get rid of it, but it is hard to remove. Some users like it, some curse it. It has been reported to be toxic to livestock, particularly when it has been the sole source of forage. In mixtures, toxic effects are apparently minimal.

All of the greasewood populations in the Great Basin that have been sampled thus far for chromosome studies have been octoploid (72 chromosomes). Populations that have been examined in Alberta, Canada, have all been tetraploid (36 chromosomes). We are actively searching for diploid populations which we expect occur somewhere in the geographical distribution of Sarcobatus.

Stop #5: Polyploid forms of Atriplex confertifolia and Atriplex tridentata

These are located 2.5 miles (4 km) farther west near the Pony Express monument. Upon arriving at the Pony Express monument, exit to the right (north) and follow the dirt road for about 50 yards (45 m). You are now in the midst of an extensive population of polyploid A. confertifolia (shadscale). Notice how uniform and dense the stand is. Glance up the valley to get a feel for the expanse of the population. Notice that most plants are about the same size, all are at about the same stage of growth and phenology. Very few other species are here.

Can you recall the diploid population? Diploid A. confertifolia plants were widely spaced, of various sizes, intermixed with many other species.

Polyploidy in this species, and apparently in most other woody chenopod species, brings with it genetic uniformity, reduced stature, and increased woodiness. Polyploids are always produced from a very small proportion of the genetic variation which is present in their diploid progenitors so are routinely very uniform. This causes them to be ecologically narrow-niched but often superbly so. Consequently polyploid populations such as this essentially saturate the landscape to which they are uniquely adapted. Diploids, being genetically flexible, occupy a variety of sites in conjunction with and in competition with a number of other species. They are therefore marvelously endowed with the capacity to accommodate changing environments. Polyploids are not. When the environment to which a polyploid is adapted changes, the polyploid is usually lost.

This is probably the principal reason for the distribution pattern of shadscale which we have thus far seen on the tour. The diploids are on the upper slopes, mingled with a variety of other shrubs, occupying a wide variety of microenvironments. They are in terrain that was above the level of the Pleistocene lakes which filled these valleys as recently as 10-12,000 years ago. They were probably in these same sites even during those pluvoglacial times. As the water receded, extensive acreages of highly uniform empty terrain became suddenly available. Each adaptive polyploid, being genetically uniform, could explosively spread out and occupy vast domains. Predictably, as successional competition unfolds during the coming centuries, many of these uniform polyploid stands will be replaced. But today we are privileged to witness the early moments of this dynamic drama and the adventive polyploids coming forth from their diploid ancestors in the adjacent junipers and sagebrush uplands.

About 0.5 mile (0.8 km) farther north, polyploid Atriplex confertifolia intergrades with, and then gives way to, a pure stand of Atriplex tridentata (Kuntze) H. and C. This is the hexaploid (6N) form which is so common in the bottom muds of old Lake Bonneville. Diploid (2N) and tetraploid (4N) forms of A. tridentata occur in Wyoming and Montana but the hexaploid is the only form here in these bottom lands which were covered by water only a few thousand years ago. A. tridentata probably came into Utah as a hexaploid and, as did the polyploid forms of shadscale, spread rapidly to occupy the rather uniform empty lake muds. It apparently is now being replaced in some places by saltgrass (Distichlis stricta (Torr.) Rydb.) and Sarcobatus vermiculatus.

Atriplex tridentata is highly palatable and nutritious. Most ranchers who have it hold it in high esteem as a forage plant. But in some places it appears to have already been grazed out and in others is being seriously threatened. Some populations would probably have long ago been destroyed were it not for its vigorous root-sprouting habit.

The rest of the large valley to the north is occupied by alternating bands of A. confertifolia, A. tridentata and Sarcobatus vermiculatus. If you would like, drive on up through them to acquire an appreciation for their magnitude and importance. For the tour, however, we will turn around here and return to the Faust road.

At the monument, turn right and proceed west toward Faust. As you drive along notice that each deep valley is occupied by polyploid A. confertifolia and A. tridentata. On the knolls, Artemisia and Chrysothamnus become abundant.

After crossing the railroad tracks at Faust, go about 0.5 mile (0.8 km) before stopping in another rather distinctly different population of polyploid A. confertifolia. Although it is a uniform stand, as was the population at the Pony Express monument, the plants are noticeably larger and more widely spaced. To the south you can see some scattered junipers. Diploid (2N) A. confertifolia plants also grow there among the junipers. It is remarkable how these different habitats are neatly matched by different chromosome races.

Stop #6: 6N Atriplex falcata

At the junction of the Faust road with Utah Highway 36 (asphalt), turn right and proceed 7.5 miles (12 km) to a "pure" stand of hexaploid A. falcata. It is easily spotted on the west side of the road as a low-growing light-colored carpet. The borrow pit is shallow so, if you wish, you can easily drive out into the Atriplex. Notice how flat and level the ground is. Can you tell why? Did you ever see a more beautiful homogenous stand of anything? This is one of my favorite overnight fireless campsites. It's so clean and handsome.

This is the only known population (or series of populations) of the 6N form of A. falcata. It has many things in common with the diploid form which we saw back at the Forest Service exclosures, but it is somewhat more woody and longer lived. Notice how abruptly it interfaces with the neighboring sagebrush. Is it invading the sagebrush? Or is the sagebrush invading the Atriplex? So far it has not been possible to detect the factors which give it such sharp borders. There doesn't appear to be any measurable edaphic factor or moisture difference. Probably the best guess is simply that it is here because it arrived first and has proven very competitive. There has not yet been time for successional processes to cause changes in composition.

As you travel on toward Tooele, a few more rivers of 6N A. falcata can be seen off to the west, but soon the landscape becomes dominated by vast populations of sagebrush and shadscale.

Tooele is the last major city on the tour until Wendover so it would be well to freshen up and gas up here before continuing.

Stop #7: Atriplex "tooelensis": A New Species.

About 6 miles (10 km) west of Tooele on highway 112 there is a "brand new" species of Atriplex. You can get a good look at it by stopping about 50 yards east of mile marker #2 east of Grantsville. It is present on both sides of the road. From a distance, it looks a good deal like A. canescens. Notice that the plants are well spaced and rather distinctly separated from the contrasting surrounding grasslands. This new species (currently referred to as Atriplex tooelensis) is a product of the hybrid A. canescens x A. tridentata. This same parentage has given rise to several other new species and a host of genetic variables from which even other species may yet be derived. We will see some more of them during the next few hours.

A. tooelensis is hexaploid (6N) like its A. tridentata parent. It has four-winged fruits like its A. canescens parent, although the fruits are smaller and irregular. Most of its other features are mosaics of the two parents or else show intermediacy. The A. canescens parent prefers sandy soils whereas A. tridentata is almost always in heavy clay soils. The soils here which are occupied by A. tooelensis is a clay loam, intermediate between those required of the parents. Flowering and fruiting time of A. tooelensis is late in the season like its A. tridentata parent. Its woody habit is more like its A. canescens parent.

Many other genetic combinations can result from the hybrids between these strikingly different parents but this particular segregant appears to be marvelously suited for this particular site. As you can see, the total population occupies not much more than 100 acres (40 ha). It is probably only a few decades old.

Stop #8: Ecological Zonation of Chenopods

About 4 miles north of Grantsville on Highway 138, the road comes close enough to Great Salt Lake to permit a look at the lakeside vegetation zones. Usually it is possible to exit on the turnoff to the east. If it is not too muddy, you can drive down onto the lake muds about 0.2 mile (0.3 km), but if it's muddy just park and walk down. This is an excellent place to see several important chenopods and also to see how they are restricted to specific ecological zones.

Farthest out into the wet muds is Salicornia pacifica Standl. (samphire). It has jointed stems, very succulent leaves and opposite branching. It is the only chenopod shrub which can accommodate prolonged submersion in these saline waters. Its monotonous uniformity in habit is, undoubtedly, a reflection of its uniform genotype which is a consequence of inbreeding.

Around the wet edges of the meadows of Salicornia is Allenrolfea occidentalis (Wats.) Kuntze (pickleweed). It also is often submerged in salt water but not for such prolonged periods as Salicornia. Although not particularly abundant right here, in many places on the shores of the Great Salt Lake, its preferred habitat is extensive and vast acreages are occupied by nothing else.

Notice that, like Salicornia, its stems are jointed and the leaves are succulent. But it differs from Salicornia in that the branching is alternate. It also stands much more erect and is considerably more woody than Salicornia. It too is genetically uniform and is consequently restricted to a narrow ecological niche.

Altitudinally above Allenrolfia is Atriplex tridentata. There is not much of it right here in this severely protracted shoreline, but in other such places it is often very abundant.

Next, up on the slopes, comes Sarcobatus. These large thorny bushes often form almost impenetrable thickets. They sometimes extend in a belt around the lake often a half mile (0.8 km) or more wide and 10 to 20 miles (15-30 km) long.

Above the Sarcobatus and sometimes growing right with it is Atriplex confertifolia.

In many places around the lake, this distinct zoning from Salicornia to Allenrolfea to Atriplex tridentata to Sarcobatus to Atriplex confertifolia is clear and distinct. Sometimes Atriplex and Sarcobatus intermingle and sometimes Salicornia and Allenrolfea intermingle but in most places they stay "where they belong."

Stop #9: An Isolated Female A. canescens Plant. (Where It All Began)

About 5 miles (8 km) farther north on this same highway (Hwy 138), there is an old railroad loading dock on the west side of the road, about 0.3 mile (500 m) south of the freeway. If the metal gate is open (it usually is), drive in and around to the far side of the loading dock. If the gate is closed, it is only a 3-minute walk. Nestled against the west embankment of the dock is a single, large female plant of Atriplex canescens. This plant bears some significant sentimental value. It was here that many of these chenopod studies got their start.

Early in our studies, seeds were collected from this particular bush as just one of the many others which we had sampled during a broad survey of the chromosome numbers of Atriplex canescens. Earlier we had found a diploid (18 chromosomes) form of A. canescens growing on the Little Sahara Sand Dunes in central Utah. All other populations which had been examined had only tetraploid (36 chromosomes) plants. When we came to this large plant growing on sand we wondered if it might be another diploid. Much to our surprise, seedlings from this plant all had 45 chromosomes! After considerable deliberation we decided that such a product could only come from a 36 chromosome x 54 chromosome parentage. So if this plant had 36 chromosomes, like that of most A. canescens plants, its sex cells would consequently each have 18 chromosomes and seeds having 45 chromosomes would be produced only if the other parent had 54 chromosomes: (its pollen would have 27 chromosomes; 18 + 27 = 45).

Since this is a lone female plant, and since the only other Atriplex species anywhere near is A. tridentata, we then reasoned, A. tridentata must be the culprit and it must be hexaploid (54 chromosomes). We didn't waste much time in checking it out. A. tridentata is indeed hexaploid! Furthermore, we found a few hybrid seedlings nearby and raised some others in the Brigham Young University nursery. From this beginning we have learned much about their fertility and potential for yielding new species, such as A. "tooelensis which we saw a few miles back.

Stop #10: The Origin of Atriplex robusta

Another new species that has recently evolved from A. canescens X A. tridentata parentage is A. "robusta." It is of very recent origin; so recent that its progenitors are still in place. It originated near Knolls, Utah, a small community about 40 miles (64 km) west of here. To get there, follow the freeway (I-80). There is an entrance to the freeway about 0.5 mile (0.8 km) north of here.

On the way to Knolls, you will see several large populations of various chenopods. One of the first is Salicornia. Lots and lots of it is growing in the wet borrow pits for the first 5 or 6 miles (8-10 km). In drier sites Allenrolfea occidentalis, Atriplex tridentata and A. confertifolia are common. Just past the Rowley exit, a large population of 8N Atriplex confertifolia can be seen off to the north.

After leaving Delle, the road rises gently to the Lakeside exit. Notice how, with increasing altitude, more grasses and fewer chenopods are present. Occasional large patches of A. confertifolia can be seen on the bottom floor or along the sides. The sharp boundaries of these populations suggest a dramatic interaction with the grasses but it is difficult to determine which way the drama is proceeding and which will be the ultimate winner.

After exiting at the Knolls exit, if traffic will permit, make a brief stop up on top before going across the overpass. From here you can see Allenrolfea occidentalis at its best. Off to the northwest as far as you can see there is nothing but Allenrolfea. This area is often flooded, but not for long. Allenrolfea's feet are always in the water; at times it's nose is too. Wherever it gets wetter, it is replaced by Salicornia; wherever it gets drier it is replaced by Sarcobatus, Suaeda or Atriplex. Off to the northeast can be seen an extensive stand of Halogeton, a troublesome introduced annual chenopod.

After leaving the overpass, the road turns west and cuts through a sand dune just before coming to Knolls. Stop on the east side of the dune for a look at a nice population of Atriplex canescens. This is one of the parents of A. "robusta." Notice its vigor. The plants appear to have many of the same characteristics found in the diploid (2N) A. canescens var. gigantea which grows on the Little Sahara Sand Dunes 100 miles (160 km) south of here. But these plants are tetraploid (4N). There is good reason to believe that these may be autopolyploids derived from the gigas diploids.

About 50 yards (45 m) to the west (you can either drive or walk) are some plants of A. tridentata, the other parent of A. "robusta." Nearby are extensive populations of A. tridentata but here you can see only a few of them. Also here is a variety of A. canescens X A. tridentata hybrids and hybrid products. Notice how each plant differs in stature, in habit, in woodiness, in leaf size and texture, and in fruit characteristics. Take plenty of time for "oohing and aahing," then go out into the median between the two freeway lanes immediately north of here where more of these hybrids can be seen. To get there, return to the overpass, cross over, and return to the sandhills by way of the freeway, then exit into the wide, well-traveled median.

In this median area, there are even more segregants from A. canescens X A. tridentata hybrids and, in addition, one form that recurs over and over again. This is the one and only segregant, among the hundreds which are possible, which so far, is sufficiently adapted to this particular habitat to have become established as a new species-- Atriplex "robusta". As you travel on down the freeway from here, you will see it over and over again. There are now thousands and thousands of them. Some have gone nearly to Wendover, 30 miles (50 km) to the west. Some have gone nearly to Delle, 40 miles (64 km) to the east. They occur only along the freeway and the freeway is less than 20 years old!

Here, then, is evolution in action. A new species is born, right before our eyes!

As you continue west on the freeway, notice that A. "robusta" is very common in some places, scarce in others. Can you guess why? Stop occasionally and take a close look at this remarkable segregant. Notice that its leaves are larger in all respects than the leaves of either of its parents. (That's hybrid vigor!) The fruits are distinctly three-toothed (sometimes more) like its A. tridentata parent, but they are at least three times as large. The plants are quite woody, a characteristic which they received from the A. canescens parent. They are also hexaploid (6N) like the A. tridentata parent.

Along with A. "robusta", a few unusually large hybrid Atriplex plants are also present on the highway shoulders. An examination of their fruits, leaves, and woodiness clearly indicates that they are backcrosses of A. "robusta" onto A. canescens. These differ considerably from plant to plant, but although they have fairly high seed fertility, they do not appear to be producing anything of significance in this environment.

The only other species that are at all conspicuous along the freeway are Allenrolfea occidentalis and, occasionally, a few plants of Suaeda fruticosa.

While you are here in this remarkable landscape, where the narrow ribbon of asphalt traverses vast expanses of salt and water, be sure to contemplate some of the other unusual spectacles. Notice, for instance, that this great expanse of salt and water is so extensive and so level that you can actually see the curvature of the earth! Also notice the logs, mountains, and bushes hanging in the sky near the horizons. The Utah Travel Bureau has gone to great expense to have this prepared just for your visit.

Our next chenopod stop is on the other side of Wendover. You will probably want to spend the night in Wendover before proceeding, but the account of the tour will continue as though we were to just keep going.

Stop #11: A rich mixture of A. canescens, A. confertifolia, and A. tridentata

Starting at about 3 miles (5 km) south of Wendover on U.S. Highway 93A, Atriplex canescens becomes increasingly abundant in the borrowpits. On the gentle east-facing slopes, above the road, A. confertifolia also becomes abundant. This population of A. confertifolia is another octoploid form, but notice how very different it is from the other octoploid populations which we have seen. This small-statured, very compact, very woody, very spiny form is admirably suited to these xeric, harsh exposures. Other forms probably wouldn't make it here at all nor would this form likely succeed in their habitat. Just as there are numerous ecological sites throughout the Great Basin to which Atriplex confertifolia is adapted, so there are numerous genetic strains to match them. Patchy environments invite patchy taxa.

Coming up from down near the lake are several rivers of A. tridentata. Here, where all three of these Atriplex species meet (A. canescens, confertifolia, and tridentata), hybrids occur among all of them. No new stabilized derivative is yet apparent, but the potential is certainly present. If (or when) the right combination comes along, it could easily and quickly provide a new adaptive taxon. In the meantime, subtle introgression of genes from each of these species into the others is permitting less dramatic, but every bit as effective, evolutionary change. The most noticeable introgression here is that of A. confertifolia into A. canescens. Because of this introgression, A. canescens is beginning to creep up the mountain. Such harsh, xeric sites could never be occupied by ordinary A. canescens, but given some A. confertifolia genes, they are apparently going to make it.

Stop #12: Atriplex dollyvardensis, another new species.

There is a large population of Atriplex "dollyvardensis" in Antelope Valley, about 20 miles (30 km) south of here. On the way to Antelope Valley, you will drive through a rich mix of wildland shrubs including several chenopods. At the upper slopes, Grayia spinosa is intermittently common along with Tetradymia spinosa H. & A., T. glabrata Gray, and Artemisia spinescens D.C. Eaton. Probably the most abundant non-chenopod shrub throughout this entire area is Chrysothamnus viscidiflorus var. stenophyllus.

Just beyond White Horse Pass, as you enter Antelope Valley, vast populations of several species of chenopods can be seen from a distance. They appear as alternating bands extending across the valley slopes. The lighter colored bands are Ceratoides lanata. There must be thousands and thousands of acres of it here. The extensive dark-gray bands (in winter and spring) are populations of Atriplex confertifolia. Sarcobatus vermiculatus appears from here as dark green bands.

Atriplex "dollyvardensis" appears as conspicuous, extensive light-gray weeds. There are thousands of acres of it. To become better acquainted with it, drive down to the bottoms and stop at about mile marker #18. Off to the west it is in almost pure culture. As you walk out into it, you will see that it is very woody. Most plants are about 20 inches (50 cm) tall. Leaves are linear and blunt. Fruits are beaked and usually highly sculptured with various protruberances.

The origin of A. "dollyvardensis" is not yet clear. Its woodiness, narrow leaves, and highly sculptured fruits suggest the influence of A. canescens. Some of its other attributes (beaked fruits, low stature, and tap roots) suggest A. falcata ancestry. Because of this and because it is hexaploid (6N), it may be an allopolyploid derived from 4N A. canescens x 2N A. falcata. But at this time, that interpretation is very speculative.

To compare it with diploid A. falcata, you may want to drive another 5 miles (8 km) due south where there is a nice clean population of A. falcata. It is located about 2 miles (3 km) south of the Dolly Varden exit on the west side of the road. Notice how it stops abruptly at the juncture with its neighbors. Notice also how much smaller, finer textured, and more herbaceous it is compared to A. "dollyvardensis". Just beyond this population, to the south, is more Ceratoides lanata and then several miles of a mixture of Grayia spinosa, Artemisia, and Chrysothamnus.

This terminates the chenopod tour. As you return to Provo you may want to review the various species which you have seen. If you can identify them at 55 mph, you know them!

Stop #13: (For good luck, and also for gigas diploid Atriplex canescens)

At the end of our tour in 1983, many of the participants elected to take a major additional excursion to the Little Sahara Sand Dunes to see the gigas diploid form of A. canescens. It's quite a long way over there but it's well worth it. For those who would like to go, here are a few directions which should increase your enjoyment of the experience.

The Little Sahara Sand Dunes (so designated by the BLM) are located in Juab County, Utah, about 20 miles (30 km) northeast of Delta, Utah. To get to them, the most direct route is to return to Tooele and then follow Highway 36 south about 50 miles (80 km) to Tintic where it joins U.S. Highway 6. Continue south on U.S. 6 for another 15 miles (24 km) where, at a crossroads, there is a well-marked sign, pointing to the "Little Sahara Sand Dunes" to the west. Cross the railroad tracks and proceed west for about 5 miles (8 km). Turn south at the sign which points to the BLM Little Sahara Recreation Area and follow the asphalt for 7.2 miles (11.6 km) to the "Jericho Picnic Area." Pull into the picnic area and park in one of the stalls facing west. Immediately in front of you, those large bushes growing on the dunes, are diploid Atriplex canescens var. "gigantea" plants. You simply must walk over and see them up close.

As you walk toward the dunes you will pass some ordinary-looking A. canescens. That's exactly what they are--ordinary tetraploid A. canescens. Every bush which is not on the dunes is tetraploid; every bush growing on the dunes is diploid. It's remarkable how they know where they belong. We have seen several other examples on the tour of such sensitive habitat sensing by specific genotypes, but none are more specific than these.

Fortunately, tetraploid and diploid A. canescens can be distinguished by means other than actual chromosome counts. As you examine the diploids, notice the large amount of new growth on the stem tips. New leader growth on diploids is usually at least twice as long as on tetraploids. This is also reflected in their longer internodes.

The gigas growth habit of diploids is also evident in fruit size, in leaf dimensions, and in total size of the plants. Some of the plants grow more than 8 feet (2.5 m) high and 20 feet (6 m) across. If you walk about 100 yards (90 m) to the north, you can see some of these huge plants not far away. If you are a good hiker you ought to go over for a close-up look.

Seedlings of diploids show the gigas growth rates right from the start. When grown alongside tetraploids in the greenhouse, diploids outgrow tetraploids, two to one. This differential is maintained all through their life even when transplanted to common gardens.

The gigas habit of the diploid is a bit puzzling. In most plants, diploids are less robust than polyploids; polyploids are usually gigas. Why then is it reversed in fourwing saltbush? The answer is not at all clear but it appears to be related to the woody habit of Atriplex. Most other reports of polyploidy have been from studies of herbaceous plants. Woody plants probably provide an entirely different scenario. For example, large sagebrushes (Artemisia), like saltbushes, have gigas diploids and smaller polyploids.

In polyploids, there is always a longer interval between cell divisions than in diploids. This is apparently simply because it takes longer to generate twice as many chromosomes prior to the next cell division. In herbaceous plants, cell growth continues during this long interval. In woody plants, however, because cellulose may be deposited in the cell walls, cell elongation may be inhibited. Some cells may even be prevented from further mitosis. As a consequence the plant may be conspicuously stunted. Whether or not this is the correct explanation awaits further information, but the remarkable reversal of gigas growth rates in these woody plants compared to herbaceous species is real.

The strict difference in habitat of diploid and tetraploid A. canescens is also somewhat of a puzzle. Why is the diploid so severely restricted to the sand dunes and why is the tetraploid so severely restricted to off-dune sites? The best guess which I have been able to come up with so far is that tetraploids are not on the dunes simply because they cannot grow fast enough to keep up with the ever-shifting sands. Why diploids are not found off the dunes is a little stickier but it may be that because of their increased succulence they are unusually attractive to herbivores and are therefore devoured before they can get established. They grow well in nurseries at a variety of sites; they do not need sand dune habitat for growth, so perhaps they are restricted to dunes primarily because of the refuge provided therein.

Neither is it clear where gigas fourwing came from. There are other populations of diploid A. canescens in southern Arizona, southern New Mexico, and Mexico but they are genetically conspicuously different from the Jericho sand dune form. Could these be relics of a formerly much wider distribution? Hopefully, answers to such questions will be forthcoming from future studies.

Because of its limited distribution, its high intrinsic academic value, and unusual esthetic worth, gigas A. canescens clearly deserves some protection. It would be a terrible loss should they ever be completely destroyed. ORV's continually take their toll. The BLM has set aside a small acreage to the north of here where ORV's are prohibited. I hope it will be enough to provide the protection needed for the survival of gigas A. canescens.

I hope you have enjoyed this brief tour into chenopod lore. The chenopods constitute a remarkable group of plants. Quite a few species of plants can handle salt, and quite a few can handle low precipitation, but the chenopods are almost alone in their capacity to handle both. No desert is quite as severe as a salt desert. Since all plants are believed to have originated in fresh water, salt deserts provide the ultimate challenge for survival on land. In that sense then, chenopods are at the latest frontiers of evolution. I salute them!

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Section 1. Distribution, Systematics, and Genetics

DISTRIBUTION, SYSTEMATICS, AND EVOLUTION OF CHENOPODIACEAE: AN OVERVIEW

E. Durant McArthur and Stewart C. Sanderson

ABSTRACT: The moderately sized (100 genera, 1,200-1,500 species) chenopod family is widely distributed. Its plants are quite common in saline and alkaline areas. In some of those areas, especially in south-central Asia, southern Australia, and western North America, woody chenopods dominate large tracts of land. A case is made for herbaceous ancestry of the family. Chenopods have $\underline{x}$=9 chromosomes with few exceptions, and polyploidy is common. The family has several adaptations for stressful environments. Ample genetic variation is available for use in manipulation and selection of plants.

INTRODUCTION

Among the families of flowering plants, the chenopod family is moderately sized with some 100 genera and 1,200-1,500 species (Cronquist 1981). For comparative purposes, two familiar families of similar size are Rosaceae (100; 2,000) and Ericaceae (70; 1,900). The largest families of flowering plants, Asteraceae (950; 20,000), Poaceae (700; 7,000), Fabaceae (600; 12,000) are on the order of 10 times as large as Chenopodiaceae (Bailey Hortorium Staff 1976). Nevertheless, the family is very important in terms of the land it occupies in the American West (Blauer and others 1976) and worldwide (Goodall 1982; West 1983). Chenopod plants, especially shrubs, are the only form of plant life found in some wet and dry saline or alkaline situations. In some areas, chenopods form, either singly or in association with other plant species, very large communities. As an example, a single population of the black saxaul tree (Haloxylon ammodendron) on the Chu River east of the Aral Sea covers approximately 1,500,000 acres (600,000 ha) (Goodall 1982). There are vast acreages of chenopod shrublands on several continents. Shrubs make a substantial contribution to Chenopodiaceae as do annual and perennial forbs. In addition, there are a few chenopod trees (Benson 1979; Cronquist 1981; Walter and Box 1983).

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This review is intended to give some insights into the family--its genetic relationships, evolution, distribution, importance to man and the landscape, and other facets that, we hope, will engender appreciation of the family.

Chenopod Characteristics

Chenopodiaceae is one of 11 families in the order Caryophyllales or Chenopodiales (Centrospermae) (table 1). These are relatively advanced plants (Takhtajan 1980) characterized by "central seeded" position of ovary placentation, coiled or curved embryos, anomalous secondary thickening of stems and roots, succulent forms, P-type sieve element

Table 1.--The families of Caryophyllales or Chenopodiales with examples.[1]

Families	Example genera
Aizoaceae	Mesembryanthemum (icicle plant)
Amaranthaceae	Amaranthus (amaranth, redroot)
Basellaceae	Ullucus
Cactaceae	Carnegiea (saguaro), Opuntia (prickly pear)
Chenopodiaceae	Atriplex (orache, saltbush), Beta (beet), Chenopodium (goosefoot), Spinaca (spinach)
Didieraceae	Diderea
Nyctaginaceae	Mirabilis (four-o'clock)
Phytoloccaceae	Phytolacca (pokeweed)
Portulaceae	Portulaca (purslane)
Caryophyllaceae	Silene (campion, pink), Stellaria (chickweed)
Molluginaceae	Mollugo

[1]From Willis and Airy-Shaw 1973; Mabry 1980. Sometimes Caryophyllales and Chenopodiales are used synonymously. When the orders are considered separately, the last two families are placed in Caryophyllales and the first nine in Chenopodiales. A traditional name for the group has been Centrospermae.

plastids, similar pollen morphology, and betalain pigments (Behnke 1976; Eckardt 1976; Cronquist 1981). The chenopod family itself shares many traits with its relatives--the other centrospermous families (tables 1, 2). The family has been divided into two (Blackwell 1977) or three subfamilies (Williams and Ford-Lloyd 1974) based on embryo, endosperm, and flower and fruit characteristics.

Table 2.--Characteristics of the family Chenopodiaceae.[1]

Shared with order	Family characteristics
"Central-seeded" ovary placentation	Leaves simple, often reduced to scales, usually alternate
Coiled or curved embryos	
Anomalous secondary thickening of stems and roots	Flowers perfect, or less often, unisexual, inconspicuous and apetalous
Succulence	Ovary superior (*Beta*= half inferior)
Betalain pigments	Fruit a utricle
Pollen morphology	

[1]Drawn from Headstrom 1978; Benson 1979; Cronquist 1981; Goodall 1982.

The family includes familiar vegetables (beet, spinach) and has or has had many other interesting uses (table 3). Shishkin (1936) emphasized the importance of chenopods: "Chenopodiaceae are more particularly associated with central Asia, where they are of considerable economic importance in desert and semi-desert areas. . . . they have no equals as pasture and forage plants and as the exclusive source of desert fuel." Similar statements could be made about chenopods in other areas although the area Shishkin describes may be the most diverse chenopod area (see Origin and Evolution section).

Some chenopods are poisonous to livestock because of oxalic acid content or accumulation of selenium (Kingsbury 1964; Davis 1972; Williams 1979). Other species cause allergies and other health problems for man (Lewis and Elvin-Lewis 1977).

GENERAL DISTRIBUTION

Plants of the family are most common in temperate climates, but the family is cosmopolitan. Eastern, Western, Northern, and Southern hemispheres all have a good representation. Chenopod plants are particularly common in (1) waste places--there are many chenopod weeds, (2) temperate saltmarshes and seaside locations, and (3) desert and semidesert areas. They are often halophytes (Cronquist 1981; Goodall 1982).

ORIGIN AND EVOLUTION

Muller (1970, cited in Raven and Axelrod 1974) suggested that the order Chenopodiales (Caryophyllales) commenced its main differentiation by Paleocene-Eocene time (ca. 55 million years ago). At that time, few angiosperm groups were differentiated. The group is old and our insight into its past is limited. Nevertheless, Raven and Axelrod (1974) were confident enough to state that "it is clear that the Chenopodiales differentiated in West Gondwanaland when Africa and South America were in closer contact." Chenopodiaceae and its near relative Amaranthaceae are now so widespread it is difficult to suggest where these families underwent their early differentiation. However, Ehrendorfer (1976) hypothesized that ancestors of Centrospermae (Chenopodiales) were plants of open, warm, dry, windy habitats with mineral soils. And Stebbins (1974) suggested that the family arose in brackish or saline habitats either along the seashore or in alkaline depressions in desert regions. Once the adaptations for these habitats were firmly established, evolutionary lines could diversify and occupy even more challenging soil types.

If, in fact, the chenopods began in Gondwanaland in the differentiating Chenopodiales matrix, they apparently became established--perhaps with several already differentiated lines--on different continents. Several evolutionarily active hotspots developed, e. g. south-central Asia, Australia, western North America. These areas were not necessarily in evolutionary concert with one another nor were the same taxa evolutionarily active in the different areas.

Herbaceous Ancestry

The ancestral chenopods were probably herbaceous. Most systemists now believe that primitive flowering plants were woody (Stebbins 1974; Takhtajan 1980; Cronquist 1981). In the case of the chenopods, however, the woody plants are probably secondarily woody (Stebbins 1974). Reasons to support the case for an herbaceous ancestry for the woody chenopods include: (1) anomalous secondary thickening of woody stems and roots (Stebbins 1974); (2) C_4 photosynthesis in many shrubs, but only a few herbs (Osmond and others 1980); and (3) more complicated, derived, sexual systems in several of the shrubs (McArthur 1977; Parr-Smith and Calder 1979; McArthur and Freeman 1982).

Data extracted from the Flora of the U.S.S.R. (Shishkin 1936) give further support to the herbaceous ancestry hypothesis. This data base should be useful because the 51 genera and 341 species listed in this flora account for about 50 percent of all chenopod genera, about 30 percent of the species of those genera, and about 25 percent of all chenopod species worldwide. If data for contiguous areas to the south were available, the point would be even more impressive. The Soviet ecologist Keller (1927) suggested that the area around Tashkent in south-central Asia was a vast outdoor laboratory for evolution of desert flora.

Table 3.--Uses for chenopods.[1]

Use	Plants
Animal feed	Mangel wurzel (Beta vulgaris), saltbushes (Atriplex spp.), winterfat (Ceratoides spp.), and others
Anthelmintic	American wormseed (Chenopodium anthelminticum)
Antihypotensive	Arthophytum spp.
Antitumor agents	Bassia spp. and Rhagodia spp.
Birdseed	Red goosefoot (Chenopodium rubrum)
Fuel[2]	Shrubby spp. (Atriplex, Haloxylon, Kochia, Salsola, etc.)
Fishbait	Sea blite (Suaeda maritima)
Grain	Quinoa (Chenopodium quinoa), and others
Herbal medicine	Goosefoots (Chenopodium spp.), oraches (Atriplex spp.), winterfat (Ceratoides lanata), sea purslane (A. portuloides), and others
Ornamental	Fire plant (Kochia scoparia)
Soap and glassmaking[3]	Glasswort (Salicornia and Salsola spp.)
Stabilizing mineral soil	Several genera including Atriplex, Camphorosoma, and Kochia
Vegetables	Beet root (Beta vulgaris), Swiss chard (Beta vulgaris), spinach (Spinaca oleracea) and pot herbs (Atriplex spp., Chenopodium spp., Sarcobatus spp., and others)

[1] Compiled from Grieve 1974; Bailey Hortorium Staff 1976; Simmonds 1976; Lewis and Elvin-Lewis 1977; Headstrom 1978.
[2] Especially in North Africa and south-central and southwestern Asia.
[3] These uses are mentioned in the Bible.

Petrov (1976) lists communities, for example, of 26 perennial plants, mostly shrubs, of which 14 are chenopods in addition to annual saltworts of the genera Salsola, Halogeton, and Suaeda. Of the 341 species listed by Shishkin, 76 percent are herbaceous (mostly annual), 23 percent are shrubs or subshrubs, and 1 percent is arborescent. Table 4 summarizes the importance of Chenopodiaceae in the south-central part of the Soviet Union and by extension to neighboring countries--but see also West 1983.

Centers of Diversity

Chenopodiaceae has wide distribution, but a few areas on a global scale are preeminent in terms of species diversity and dominance. These are south-central Asia, southern Australia, western North America, and to a lesser extent western South America and the Mediterranean Basin.

South-central Asia.--This center of diversity is larger than any other, both in terms of number of species (table 4) and in area of land occupied by chenopod species (Goodall 1982; West 1983). Even though herbaceous plants are more numerous in the number of species, the woody forms are the landscape dominants. In this area, two Haloxylon

Table 4.--Chenopod genera of the U.S.S.R.[1]

Genera with greater than 10 species	Number of species: U.S.S.R. Total	U.S.S.R. Shrubs	World	Other genera of interest	Number of species: U.S.S.R. Total	U.S.S.R. Shrubs	World
Salsola	68	[2]26	120	Kochia	8	1	45
Corispermum	34	0	55	Beta	5	0	13
Atriplex	33	3	250	Camphorosoma	4	2	10
Chenopodium	30	0	250	Halogeton	3	0	4
Suaeda	27	3	100	Haloxylon	3	[2]3	5
Anabasis	23	22	30	Ceratoides	2	2	7
Halimocnemis	11	0	12	Spinaca	2	0	3
Petrosimonia	11	0	11				

[1] Extracted from Shishkin 1936; Willis and Airy-Shaw 1973.
[2] Includes two trees.

Figure 1.-- Distribution of saxaul trees (Haloxylon) in south-central Asia (from Petrov 1976).

and two Salsola species reach a tree stature of 20 feet (6.1 m) or more in height (Shishkin 1936; Petrov 1976). The areas occupied by saxaul trees (Haloxylon) are illustrated in figure 1. Collectively, H. ammodendron and H. persicum extend 85° longitudinally and 25° latitudinally. As we pointed out earlier (see Chenopod Characteristics), chenopods are valuable fodder and fuel plants in this area (Shiskin 1936; Petrov 1976).

Southern Australia.--Another area for chenopod diversity and differentiation is Australia where there are 23 chenopod genera of which 20 include endemic species (table 5)--sixteen of the genera are endemic. In all, Australia has 206 chenopod species of which 192 are endemic. The chenopod genera occurring in Australia have a worldwide total of about 970 species (Burbridge 1963; Willis and Airy-Shaw 1973). Many of the Australian species are shrubby. Goodall (1982) maintained that the chenopod flora of Australia, like the landform on which it occurs, is mostly old and relatively stable. See Barlow (1981), however, for an excellent discussion detailing diverse evidence and viewpoints for younger and older floral components and floras. The most common dominants are Atriplex vesicaria, A. nummularia, A. rhagodiodies, Maireana sedifolia, M. pyramidata, M. aphylla, M. astrotricha, Rhagodia spinescens, and R. nutans--that is, saltbushes (Atriplex and Rhagodia) and bluebushes (Maireana) (Oxley 1979). Chenopods, especially the perennials, are much more common in arid southern and central Australia than in the north. One exception is northern bluebush (Chenopodium auricomum), which extends well into Queensland and the Northern Territory (Oxley 1979).

Although the chenopod shrublands are much used by domestic animals in Australia as elsewhere, some Australian range managers view them as less valuable than the ephemerals that replace them as a result of heavy browsing (Wilson 1969; Milthorpe 1970; Wilson and Tupper 1982). The ephemerals on some Australian rangelands are more palatable to sheep and just as nutritious as the shrubs. The chenopod shrubs, however, are extremely valuable in times of drought when the ephemerals are not present. In Australia, as in North America, shrubs and shrub management evoke arguments among land stewards as to their relative merits. Chenopod

shrublands have been severely modified in some Australian areas by livestock use (Jones 1970; Graetz and Howes 1979) as they also have been in the Middle East (Sankary 1976) and in western North America (Holmgren and Hutchings 1972; West 1983; Blaisdell and Holmgren[1]).

Western North America.--The third and final area of chenopod diversity we will examine is North America. This area has a rich chenopod flora that apparently has recent and current evolutionary activity, especially among the shrubby Atriplexes (Stutz 1978, these proceedings). However, North America is not as taxonomically rich as southern Australia and south-central Asia (table 5). Stutz (1978) has made a case for recent, rapid evolution in shrubby Atriplex in western North America. Axelrod (1950; 1979), Wolfe (1975, 1978), and others have shown that the habitats available to woody chenopods were not available or were much smaller until recent times.

Table 5.--Chenopod endemism.[1]

Area	Number of genera: Total	Number of genera: Endemic	Percent
U.S.S.R.	51	12	[2]24
Australia	23	16	70
North America	23	7	30
Utah	17	4	[3]24

[1]Data sources: Standley 1916; Shishkin 1936; Burbridge 1963; Welsh and others 1981. Follows taxonomy of Willis and Airy-Shaw 1973.
[2]Low as a measure of south-central Asia because many generic distributions cross southern border.
[3]Includes North American endemics.

An examination of the worldwide distribution of Atriplex confirms high diversity for the genus in North America. The preeminent position of Atriplex in North America can be seen in table 6. Three genera (Grayia, Sarcobatus, and Zuckia) are endemic. The other five (Allenrolfea, Atriplex, Ceratoides, Kochia, and Suaeda) have endemic species, but have richer areas of differentiation elsewhere. Atriplex is well differentiated in North America as well as other locations. There are 18 North American genera that include herbaceous species; five genera (Bassia, Beta, Axyris, Salsola, Spinaca) are naturalized and three genera (Aphanisma, Cycloloma, Meiomera) are endemic (Standley 1916; Willis and Airy-Shaw 1973). Osmond and others (1980) divided the world into nine Atriplex species distribution areas. In terms of Atriplex species endemism, South America was highest with 86 percent of its 73 species endemic; North American next with 78 percent of its 59 species; and then Australia with 68 percent of its 59 species. None of the other areas exceeded 42 species or 40 percent endemism. We point out, however, that the Osmond and others analysis divided south-central Asia into three separate areas which are not necessarily natural. The analysis did not include undescribed Atriplex taxa in North America that Stutz (1978, these proceedings) intends to formally describe. Data from Atriplex DNA homologies (Belford and Thompson 1981a, 1981b) suggest that the major period for separation of Atriplex into phyletic lines occurred 30-35 million years ago, at the time of C_3 and C_4 photosynthetic pathway separation in the genus. Differentiation within the lines has apparently taken place at different rates in different places for example, relatively less over a longer time in

Table 6.--Distribution and growth habits of chenopod species with affinities to North American chenopod shrubs.[1]

Genus of North American shrub	Number of species: Shrubs, western USA	Number of species: All forms, world	Extra North American distribution	Nonshrub growth habits
Allenrolfea	1	3	Northern hemisphere, South America	--
Atriplex	18	250	Worldwide	Herbs
Ceratoides	1	7	Eurasia	--
Grayia	2	2	--	--
Kochia	1	45	Eurasia	Herbs
Sarcobatus	2	2	--	--
Suaeda	3	50	Worldwide	Herbs
Zuckia	1	1	--	--

[1]Compiled from Standley 1916; Willis and Airy-Shaw 1973; McArthur 1984.

[1]Blaisdell, J. P.; Holmgren, R. C. Managing Intermountain rangelands--salt-desert shrub ranges. Gen. Tech. Rep. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station. In press.

Australia (Barlow 1981) as compared to more recent differentiation in North America (Stutz 1978). All Australian Atriplex is apparently C_4 whereas other Atriplex-occurring areas include both C_3 and C_4 species (Osmond and others 1980).

Chenopod Chromosomes

The family Chenopodiaceae is remarkably stable in chromosome base numbers--predominantly x=9 with only rare aneuploidy (table 7; Raven 1975). However, polyploidy is quite common (table 7).

Table 7.--Chromosome number patterns in Chenopodiaceae.[1]

Chromosome numbers	
Base number	Number of genera
6	1
8,9	1
9	43
12	2

Polyploid chromosome number patterns	
Pattern	Number of genera
2x	26
2x-4x	6
2x-6x	1
2x-6x, 12x	1
2x-8x	2
2x-8x, 12x	1
2x-12x	1
4x	7
4x-6x	1
4x-8x	1

Number of species[2]					
2x	4x	6x	8x	10x	12x
257	114	34	11	3	2

[1]Data compiled from Ornduff (1967); Federov (1969); Moore (1973, 1974, 1977); Nobs (1980); Goldblatt (1981); McArthur and Sanderson (unpublished data on file at the Shrub Sciences Laboratory, Provo, Utah).

[2]Counts the species, e.g., Atriplex canescens, A. confertifolia, A. vesicaria, Kochia prostrata, etc., that are polyploid in each ploidy level at which they are known.

Diploids (2x) and tetraploids (4x) are common, but some taxa are known up to dodecaploid (12x). There are polyploid taxa at both the generic and specific levels. For example, the North American species Atriplex canescens (2x-12x) (Stutz and Sanderson 1979) and A. confertifolia (2x-10x) (Stutz and Sanderson 1983), the Eurasian Kochia prostrata (2x-6x) (Herbel and others 1981; McArthur and Sanderson[2]), and the Australian A. vesicaria (2x-6x) are continent-bridging, vigorous polyploid species complexes.

Chenopod chromosomes are small. Atriplex chromosomes, for example, are only about 1 μm long (McArthur 1977). The average Atriplex genome is only 12 percent the size of a pea (Pisum) genome although the Atriplex genome includes two additional chromosomes (Belford and Thompson 1981a). The spinach genome is about one-third larger than that of Atriplex, but has a third less chromosomes. Chromosomes of shrubby Atriplexes are difficult to karyotype because of their small, rather uniform nature (Stutz and others 1975; McArthur 1977; Nobs 1980; McArthur and Sanderson[2]). Gustaffson (1972, 1974) has used paracentric inversions to unravel genetic relationships among populations of the Scandinavian herbs Atriplex longipes and A. triangularis.

[2]McArthur, E. D.; Sanderson, S. C. Data on file at the Shrub Sciences Laboratory, Provo, Utah; 1983.

BREEDING SYSTEMS

Most chenopods are wind pollinated with small inconspicuous flowers. Flowers may be perfect (bisexual) or unisexual--the plants then monoecious or dioecious (Benson 1979; Cronquist 1981). The most advanced plants (see Origin and Evolution), the C_4 shrubs, are those with derived sexual systems. Derived, we think, by being specialists to take better advantage of scarce resources in a stressful environment. The C_4 shrubs are basically dioecius or subdioecious. An example is the apparent trioecious system of tetraploid Atriplex canescens (McArthur 1977; McArthur and Freeman 1982). In that system there are not only constant male and female plants, but also a labile group that may be male, female, or monoecious depending in part on environmental stress. These labile plants, we believe, react to environmental stress (winter cold, drought, crowding) by moving away from female function in physiologically stressful times. Some other genera, notably the C_3 shrubs Sarcobatus and Grayia, are monoecious but vary their particular investment in male and female function from dry to mesic sites (Sarcobatus vermiculatus--Freeman and others 1981) and from year to year (Grayia brandegei--McArthur and Blauer[3]). We believe these monoecious systems are more primitive than the subdioecious ones, but that the two kinds of systems are corollary to one another. And, that both kinds of systems have evolved to allow their species to more efficiently occupy stressful, heterogenous, patchy environments.

ADAPTATION TO STRESSFUL HABITATS

Chenopod plants have undergone several adaptive modifications to enable them to survive in difficult environments (Goodin 1975; Goodall 1982):

[3]McArthur, E. D.; Blauer, A. C. Data on file at the Shrub Sciences Laboratory, Provo, Utah; 1983.

C_4 and CAM photosynthesis[4]
Seed dormancy mechanisms
Reductions in leaf surface areas
Hairs covering epidermis
Xeromorphy (thick cuticle and recessed stomata)
Deep root systems
Ephemeral roots after rains
Internal water potential capability
Tolerance to salinity

That they survive, even thrive, in some of the most inhospitable habitats is well known. Atriplex confertifolia is photosynthetically active from 23° F (5° C) to 122° F (50° C)--the widest range known for any plant (Caldwell 1972).

Sodium, a poison to most plants, is a stimulant for many chenopods and even an essential nutrient for some (Kleinkopf and others 1975; Blauer and others 1976; Goodall 1982). Flowers (1934), in a classic study on the vegetation of the Great Salt Lake region, showed the successional order for plants from the lake shore out (a saline gradient halosere) to be: Salicornia rubra → S. utahensis → Suaeda erecta → Allenrolfea occidentalis → Distichlis spicata → small Poaceae and Brassicaceae herbs → Atriplex spp. All of these plants except Distichlis and the herbs are chenopods. Branson's group (Branson and others 1967, 1976; Miller and others 1982) has studied the tolerance to internal moisture and soil moisture stress for several areas and species in the salt-desert shrub type of the Western United States. Shrubby chenopods were able to handle stress better than any other species they studied.

GENETIC VARIATION

Each taxon has different amounts of variation, a point made in the Evolution and Origin section. Nevertheless, in general, most species have substantial genetic variation. Atriplex canescens, which has received considerable study, harbors abundant variation (table 8). Some other wide-ranging species complexes, for example, Kochia prostrata, are in all likelihood equally variable. Goodman (1973) documented ecotypic variation for several chenopod shrubs.

The variation in western shrubs like Atriplex canescens offers ample opportunity for use of natural ecotypes (McArthur and others 1983) or selected material (McArthur and others 1984) for use in revegetation efforts. There is great opportunity to use and enhance valuable resources--the chenopod shrubs.

[4]The C_4 and CAM photosynthesis systems are thought to be more efficient in hot climates than the conventional C_3 system. However this has not been practically demonstrated. For example, Ceratoides lanata (C_3) and Atriplex confertifolia (C_4) are equally efficient on an annual basis in Curlew Valley, Utah. Ceratoides is more efficient in the spring, but Atriplex is more efficient in summer (Caldwell 1972).

Table 8.--Characteristics of Atriplex canescens which show variability between sites or accessions.

Characteristic	References
Soil salinity	Northington and Goodin 1975; Welch 1978; Richardson and McKell 1980.
Ash content	Welch 1978
Crude protein	Gamrath 1972; Welch 1978; Welch and Monsen 1981
Stem rooting	Van Epps and McKell 1978; Richardson and others 1979.
Palatability	Van Epps, unpublished[2].
Winter hardiness	Van Epps 1975; Kay and others 1977.
Seed production, fill, and germination	Plummer and others 1966; Springfield 1970; Gamrath 197[illegible]; Stutz and others 1975; Gerard 1978.
Sex expression	Stutz and others 1975; McArthur 1977; McArthur and Freeman 1982.
Chromosome number	Stutz and others 1975; Stutz and Sanderson 1979.
Growth rate and form	Plummer and others 1966; Stut[illegible] and others 1975
Allozymes	McArthur and others unpublished[3]

[1]Adapted and expanded from McArthur and others, 1983.
[2]Data on file, Snow Field Station, Ephraim, Utah.
[3]McArthur, E. D.; Sanderson, S. C.; Freeman, D. C. Isozymes of an autopolyploid shrub, Atriplex canescens (Chenopodiaceae), manuscript in review.

The family through its wide distribution and ample differentiation, has been and will continue to be useful in a multitude of ways (table 3). Its forbs, shrubs, even trees, are often found in inhospitable environments where they usually enhance life of other organisms including mankind. We must remember, however, that some species can be weedy or poisonous.

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Atriplex HYBRIDIZATION IN WESTERN NORTH AMERICA

Howard C. Stutz

ABSTRACT: Interspecific hybridization is unusually common in the genus Atriplex in western North America. This stems from numerous contacts of species which were until recently geographically separated and also from selective advantages in habitats made available by the demise of Pleistocene lakes. The rich gene pools which have been provided by this extensive hybridization have resulted in the origin of many new taxa.

INTRODUCTION

In controlled experiments it has been shown that selection against interspecific hybrids results in rapid accumulation of reproductive isolation barriers, whereas selection for hybrids quickly erodes them (Koopman 1950, Wallace 1954, Knight 1956, Kessler 1966). Consequently, if environments are available which enhance the probability of survival of hybrid products, hybridization will expectedly be more common than in areas where hybrids are at a severe disadvantage. This has been amply demonstrated in many groups of plants and animals (e.g. Muller 1952, Ehrman 1965, Grant 1966). Since stable environments ordinarily precipitate well defined species, each of which is superbly and uniquely adapted to specific niches, hybridization in them will expectedly be rare (Epling 1947, Anderson 1948). In disturbed or rapidly changing environments, on the other hand, where opportunities are available for new genotypes, hybridization will expectedly be much more common (Weigand 1935, Epling 1947).

This is graphically illustrated in Atriplex. In Australia, where the salt deserts which are now occupied by Atriplex and other chenopods have had a relatively long quiescent geological history (Barlow 1981), Atriplex hybrids are rare. But in western North America, where there have been extensive, recent, geological disturbances, a rich array of new environmental opportunities has been provided, and hybridization is rampant (Stutz 1978).

The second major contributor to natural hybridization derives, in part, from the first. When species coexist in environments which select against hybrids, isolation barriers will ordinarily differ from area to area and from species to species. Because the barriers are established as avenues to prevent hybridization between specific sympatric species they are almost always ineffective when applied to new contacts. Consequently species which are brought together after long periods of isolation will have fewer operative reproductive barriers than species which have been together for long periods of time without advantaged hybrid products (Grant 1966).

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Atriplex HYBRIDIZATION IN NORTH AMERICA

Interspecific hybridization in Atriplex in western North America is abundant. The dramatic climatic changes which came at the end of the Wisconsin pluvoglacial, causing the demise of old Lake Bonneville and other Pleistocene lakes, provided a myriad of new habitats into which a variety of species could synchronously migrate. Southern species migrated northward, northern species came south, eastern species migrated to the west, and western species to the east. The Great Basin became the "Great Melting Pot." Related species without former contact intermingled and hybridized freely in this new arena. Having no preformed reproductive isolation barriers, having numerous available unoccupied habitats, and acquiring numerous advantages from hybridization, hybrid products were, and still are, unusually common.

The principal Atriplex species which have entered this "Basin of Promiscuity" are A. canescens, A. obovata, A. polycarpa and A. confertifolia from the south; A. tridentata, A. gardneri, and A. falcata from the north. Some hybrids are very common (e.g. A. canescens x A. tridentata) (Stutz and others 1979); some hybrid products have become well-established new taxa (e.g. A. canescens x A. gardneri--- A. aptera) (Nelson 1902). Many have formed extensive hybrid swarms which, although still too genetically flexible to be considered distinct taxa, contain the genetic wherewithal for producing many new forms; several others are already well established adaptive species awaiting nomenclatural designation.

A. canescens appears to be particularly prone to interspecific hybridization. Some of the best-known and significant hybrids are as follows:

1. A. canescens x A. gardneri -- A. aptera (Nelson 1902).

These hybrid products are common throughout most of Montana, northeastern Wyoming, and western South Dakota. Each population is genetically unique but they all are well adapted to heavy clay, alkaline soils, particularly on the banks of tributaries of the Missouri River. "Wytana saltbush" is one of the many forms of this remarkable "hybrid species".

2. A. canescens x A. tridentata has yielded several important new taxa (Stutz and others 1979) including, but not restricted to, the following:

   a. Near Tooele, Tooele Co. Utah, a hexaploid taxa occupies about 100 acres of pasture land. It is well suited to heavy clay soils, is late flowering, and has a few other tridentata-like attributes but otherwise is much like the tetraploid A. canescens which grows nearby.

   b. Abundant throughout Reese Valley, Lander Co. Nev., is a highly variable product, not yet settled-down to a single adaptive theme. These variables could provide a number of new taxa if appropriate habitats emerge.

   c. Along the shoulders of I-15 between Wendover, Nev. and Delle, Ut. is a new, particularly robust taxa. It has tridentata-like fruits but also considerable woodiness and tall stature acquired from A. canescens.

3. A. canescens x A. confertifolia is a rather common hybrid. Introgression has produced several improved forms adapted to harsher sites than A. canescens can generally tolerate.

4. A. canescens x A. falcata appears to be the parentage of A. bonnevillensis (Hanson 1962). This hybrid "species" is still genetically highly flexible.

5. A. canescens x A. cuneata is a very common hybrid in eastern Utah and western Colorado. Introgression is common into both parents but no specific derivative has yet been described.

6. A. canescens x A. polycarpa has given rise to A. laciniata, a well adapted although variable species in the Mohave Desert. It appears to be an allopolyploid but of polyphyletic origins.

7. A. canescens x A. garrettii has produced A. navajoensis (Hanson 1962) in a narrowly endemic region south of Lake Powell, Ariz.

Other common, important Atriplex hybrids include:

A. canescens x A. obovata
A. confertifolia x A. cuneata (A. neomexicana)
A. confertifolia x A. corrugata
A. confertifolia x A. obovata
A. cuneata x A. corrugata
A. polycarpa x A. obovata
A. polycarpa x A. linearis
A. polycarpa x A. confertifolia

As a result of this rampant interspecific hybridization, Atriplex is among the most genetically rich of all plant genera. It is, many times over, the most genetically variable of all chenopods in western North America. Whereas each of the other chenopod genera contain only one or two species, Atriplex consists of more than 20 named species and at least that many more well-defined yet-to-be-named taxa. Hybrid swarms and introgressive products have provided myriads of new genotypes which are, even now, exploring numerous habitats available as a result of dramatic climatic and geological changes in post-Pleistocene geography. Besides the numerous species which have emerged and which are even now emerging in natural settings, the potential for deliberate breeding and selection of varieties suited for specific use on ranges, mine spoils, and other disturbed sites is nearly unlimited.

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BIG SAGEBRUSH-WINTERFAT AND BIG SAGEBRUSH-NUTTALL SALTBUSH MOSAIC VEGETATION IN SOUTHWESTERN IDAHO

Dana L. Yensen and Graham W. Smith

ABSTRACT: We described and mapped two desert shrub communities, a big sagebrush (Artemisia tridentata Nutt.)-winterfat (Ceratoides lanata [Pursh] J. T. Howell) mosaic and a big sagebrush-Nuttall saltbush (Atriplex falcata [Jones] Standl.) mosaic. The mean age of the winterfat population was 72 years; the mean age of the Nuttall saltbush population was 24 years. Recruiting of both winterfat and Nuttall saltbush has declined in recent years. Winterfat alternes are long-established. The presence of Nuttall saltbush may be disturbance-related.

INTRODUCTION

Two adjacent mosaic communities were investigated in the northwestern portion of the Birds of Prey Study Area in Ada County, southwestern Idaho. One mosaic was composed of alternes dominated by big sagebrush (Artemisia tridentata Nutt.) and winterfat (Ceratoides lanata [Pursh] J. T. Howell). The other was composed of alternes of big sagebrush and Nuttall saltbush (Atriplex falcata [Jones] Standl.). These mosaic communities were broadly ecotonal between big sagebrush communities to the north and salt-desert shrub communities to the south. The study area lies on the southwestern portion of the Snake River Plain, a basalt plateau. The topography is rolling. Soils supporting the mosaic communities are deep silt loams and fine sandy loams (USDA Soil Conservation Service and others 1980). Annual precipitation, most of which falls in winter and spring, averages 10 in (25.4 cm). Summers are hot and dry and winters are mild. Cattle and sheep graze the area in spring and fall (USDI, Bureau of Land Management 1979).

Two photographs taken of part of the big sagebrush-winterfat mosaic around 1900-10,[1] show that this mosaic existed at the turn of the century. Beginning in the 1870's, the area suffered many decades of grazing abuse, and rapid reduction in the acreage occupied by winterfat occurred. Though there were many historic references to the presence of winterfat, we could find none to Nuttall saltbush (Yensen 1980). The lack of early references to Nuttall saltbush could be explained in two ways. The plant is neither as conspicuous nor as easily identified as winterfat, especially when dormant. Early observers may have included it in descriptions of shadscale (Atriplex confertifolia [Torr. & Frem.] Wats.) or other Atriplex vegetation. Alternatively, Nuttall saltbush may not have then been abundant enough to warrant notice.

Heavy grazing may favor Atriplex species at the expense of winterfat (Holmgren and Hutchings 1972). Also, we observed small areas (usually less than 1 acre [0.405 ha]) where Nuttall saltbush has replaced winterfat near stock watering tanks and sheep bedding camps. Both historic records and these observations suggest that while winterfat was a long-established component of the mosaic, Nuttall saltbush could be adventive.

METHODS

In 1979, stands of the mosaic communities were delineated and mapped on USGS 7.5-minute topographic maps, using color aerial photographs. All boundaries were ground-checked. Only stands 40 acres (16.2 ha) or larger were mapped. Twenty-two stands of big sagebrush-winterfat mosaic (25,823 acres [10,450.42 ha]) and ten stands of big sagebrush-Nuttall saltbush mosaic (7,062 acres [2,857.95 ha]) were identified. The vegetation in each stand was sampled in 1979 using the canopy coverage technique of Daubenmire (1959). Canopy coverage of all species was estimated from forty 10.8-ft^2 (1-m^2) plots at 34-ft (10-m) intervals along a 1,312-ft (400-m) transect in each stand. Fifteen circular shrub density plots were sampled along each canopy transect in the manner of Asherin (1973). Each shrub density plot was 1/300 acre (0.0014 ha). The number of shrubs in the plots and the average height were recorded for each species.

In the fall of 1981, much of the area occupied by big sagebrush-Nuttall saltbush mosaic burned, leaving only a few small remnant stands no larger than a few dozen acres.[2]

In 1983, two sampling sites were located where ecotones between alternes of winterfat and Nuttall saltbush were present. Two transect sets were established 196.85 ft (60 m) apart at each sampling site. Each of the transect sets consisted of nine parallel sampling lines, each

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[1]Bowen, C. F. Photos #25 and #26, Sinker Butte on the Snake River Plateau, 8 miles E. of Murphy, 30° E. Available from the U.S. Geological Survey Photographic Library, Denver, Colo.

[2]USDI, Bureau of Land Management, Boise, ID. District unpublished fire records; 1981.

60 ft (15.24 m) long and 131.23 ft (40 m) apart (fig. 1). The center line of the nine, called line 0, was arbitrarily placed in the visual center of the ecotone, along its length. Lines in each transect set were numbered from line 0 into each alterne: lines 1W, 2W, 3W, and 4W were placed 131.23 ft (40 m), 262.47 ft (80 m), 393.70 ft (120 m), and 524.93 ft (160 m), respectively, into the winterfat alterne. Lines 1N, 2N, 3N, and 4N were placed 131.23 ft (40 m), 262.47 ft (80 m), 393.70 ft (120 m), and 524.93 ft (160 m), respectively, into the Nuttall saltbush alterne. Lines 3 and 4 were located well within "pure" assemblages of each respective shrub.

Figure 1.--Schematic diagram of the nine sampling lines of a transect set. Lines are 60 ft (15.24 m) long and 131.23 ft (40 m) apart. Dark areas are big sagebrush alternes.

On each sampling line, the total number of line hits of living and dead individuals was recorded for both species. We searched for seedlings on all sampling lines. At 2-ft (60.96-cm) intervals on each sampling line, the winterfat or saltbush individual nearest that point was removed for aging by vascular ring count (30 plants per line). A total of 1,183 shrubs were ring-counted, 484 winterfat and 619 Nuttall saltbush.

Since woody chenopods do not form vascular rings in the same manner as do most other woody dicots (Stebbins 1972) and, rarely, may produce more than one vascular ring per year (Stewart and others 1940), ages determined by counting vascular rings in winterfat and Nuttall saltbush may not be as accurate as ages assigned by vascular ring-count to species such as big sagebrush.

Also, since these chenopods have very complacent rings, their ages cannot be determined by correlation with nearby sensitive-ring species like big sagebrush (Davis and others 1972). However, several workers have found aging chenopods by vascular ring count to be a reliable and useful technique (Stewart 1935; Stewart and others 1940; Strickler 1956). Because both winterfat and Nuttall saltbush are chenopods, the technique is likely to be comparative. In our results, age in years represents the highest continuous count of vascular rings per shrub.

RESULTS

Canopy coverage of all major species revealed great similarities in the structure and composition of the two communities (tables 1 and 2). Average densities and heights of big sagebrush were also similar in both mosaics.

Table 1.--Composition of big sagebrush-winterfat community.

Species	Percent canopy coverage	Percent frequency	Density (no. per acre)	Height (inches)
Artemisia spinescens	.6	27	141.80	5.31
Artemisia tridentata	7.2	100	1,537.27	20.12
Atriplex confertifolia	.1	9		
Grayia spinosa	1.0	36	113.64	20.20
Ceratoides lanata	10.8	100	8,419.71	6.61
Bromus tectorum	5.4	55		
Festuca octoflora	1.6	59		
Poa secunda	5.1	95		
Sitanion hystrix	1.3	77		
Salsola iberica	trace	5		
Sisymbrium altissimum	trace	5		
Descurainia spp.	.9	55		
other forbs	2.1	82		

Table 2.--Composition of big sagebrush-Nuttall saltbush community.

Species	Percent canopy coverage	Percent frequency	Density (no. per acre)	Height (inches)
Artemisia spinescens	.2	10	139.98	11.42
Artemisia tridentata	8.9	100	1,587.94	20.71
Atriplex falcata	3.7	100	3,231.89	4.72
Grayia spinosa	.6	30		20.08
Bromus tectorum	6.5	50		
Vulpia octoflora	.9	50		
Poa secunda	5.3	80		
Sitanion hystrix	1.0	70		
Descurainia spp.	.7	50		
other forbs	2.1	60		

Dead plants of winterfat were uncommon on all sampling lines. Dead saltbush plants on the saltbush sampling lines were more numerous as the distance from the ecotone increased (fig. 2). Fewer individuals of winterfat and Nuttall saltbush were found on 0 (ecotone) and 1W lines than on any other sampling lines. No seedlings of either species were encountered. No fire-charred living or dead shrubs were found.

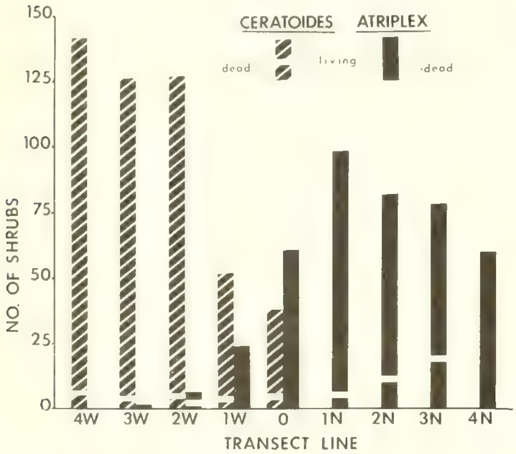

Figure 2.--Frequency (line hits) of living and dead winterfat and Nuttall saltbush on sampling lines (60 ft [15.24 m] long, 131.23 ft [40 m] apart), across ecotones between alternes of each.

The youngest winterfat individual was 22 years old, and the oldest 136 years. The mean age of winterfat was 72 years (fig. 3). Most winterfat were older than the ages we recorded; only 7 of 484 winterfat we aged had intact cores. The youngest Nuttall saltbush was 3 years old, and the oldest 61 years. The mean age of Nuttall saltbush was 24 years (fig. 4).

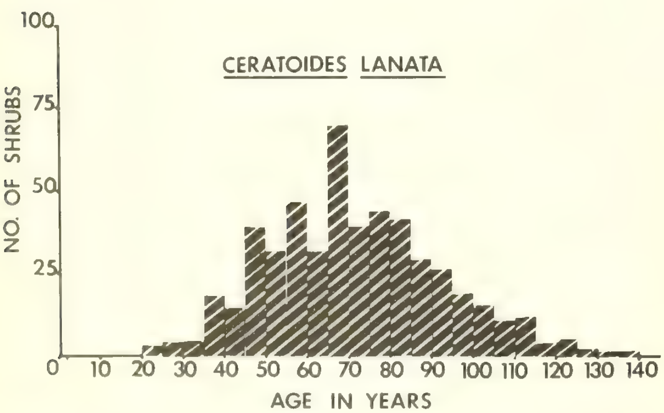

Figure 3.--Age distribution of winterfat population in the sampling area.

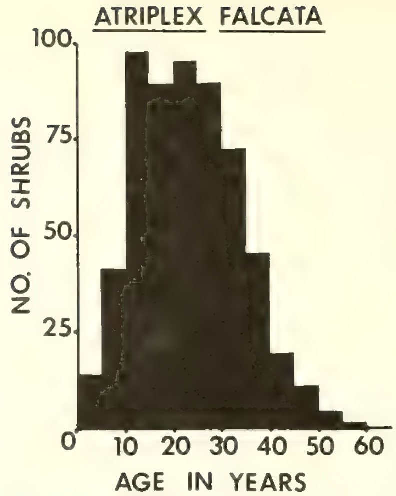

Figure 4.--Age distribution of Nuttall saltbush population in the sampling area.

Ages of plants on each sampling line were compared using one-way ANOVA (Nie and others 1975) with *a priori* contrasts using the *t* statistic. Mean ages of winterfat were not significantly different between sampling lines except between lines 2W and 4W ($p<0.01$); age of winterfat on ecotonal lines (0) was significantly different from the age of winterfat on each of the other lines (table 3).

Table 3.--Comparisons among mean ages of winterfat (W sampling lines) and Nuttall saltbush (N sampling lines) in the ecotone (0) and at increasing distances from it (*a priori* *t* contrasts). (See fig. 1 for sampling line scheme).

	1W	2W	3W	4W	0 W	0 N	1N	2N	3N	4N
1W	--									
2W	ns	--								
3W	ns	ns	--							
4W	ns	.01	ns	--						
0 W	.05	.001	.05	ns	--					
0 N	.001	.001	.001	.001	.001	--				
1N	.001	.001	.001	.001	.001	.001	--			
2N	.001	.001	.001	.001	.001	.001	ns	--		
3N	.001	.001	.001	.001	.001	.05	ns	.01	--	
4N	.001	.001	.001	.001	.001	.001	ns	ns	ns	--

Winterfat plants scattered through the saltbush alternes were so rare that none were recorded on any of the sampling lines. However, saltbush was present in small amounts in the winterfat alternes (fig. 2).

DISCUSSION

If either winterfat or Nuttall saltbush were invading the adjacent alterne of the other species, we would expect the invading species to be younger closer to and within the ecotone. The mean age of a non-invading shrub species would be similar within the ecotone and at all distances from it. For an invading species, one would expect fewer dead plants and more seedlings closer to the ecotone, while for a non-invading species one might expect more dead plants and fewer seedlings closer to the ecotone.

Winterfat has long occupied the winterfat alternes, since each winterfat sampling line (and all 0 lines) had winterfat plants over 100 years old. Nuttall saltbush is obviously shorter-lived than winterfat (figs. 3 and 4). The lower mean age of saltbush on the ecotone lines may indicate that saltbush is expanding into the winterfat alternes. Although mean winterfat ages were lower on ecotone lines than elsewhere, this is the result of no winterfat in the 104 to 136-year range in the ecotone. In fact, winterfat on the ecotone lines had the highest minimum age recorded on any group of sampling lines (34 years), indicating that this species is less reproductively successful in the ecotone.

Dead winterfat were uncommon on all sampling lines. As we would expect for an invading species, no dead saltbush were recorded on lines 0 or on lines 1W, and dead saltbush in the saltbush alternes were more frequent at increasing distances from the ecotone (fig. 2). Total numbers of dead saltbush were much higher than total numbers of dead winterfat. This can be attributed to the shorter life span of saltbush, with the shorter "turnover time" generating more dead plants (Bamberg and others 1980). It is also possible that there are many dead saltbush because this species is subject to periodic insect attacks, which can result in high mortality.[3] The low numbers of both winterfat and Nuttall saltbush on lines 0 and 1W may indicate competition between the species where both are present in numbers.

One result of our investigation was the discovery of diminished levels of recruiting of both species in recent years, especially winterfat. Recruiting of Nuttall saltbush has fallen off only during the past decade. However, the winterfat population has recruited virtually no new individuals in 20 years. We found more winterfat older than 100 years than winterfat younger than 30 years.

Strickler (1956) called a Nevada winterfat population "overmature." Plants 2 to 6 years old made up 15 percent of the population; 70 percent of the plants were from 35 to 65 years old.

Stewart (1935) found a Utah winterfat population in which 7 percent of the plants sampled had ring counts of 21 or fewer. He stated that this population was in danger of extinction in one or two plant generations. Norton (1978) studied a Utah winterfat community in which just over half of the plants were what he called "old"--40 years old or older. In comparison, the winterfat age profile in our sampling area is heavily skewed toward very old plants.

Stewart, Cottam, and Hutchings (1940) studied the vegetation of three adjacent Utah valleys and aged the winterfat populations in each by vascular ring count (fig. 5). Snake Valley they described as lightly grazed, and grazed only in winter. Pine Valley was characterized as heavily grazed during the previous 20 years and moderately grazed before that time. Wah Wah Valley had been heavily grazed from the time of white settlement until the time of their study. All populations contained individuals less than 10 years old. Snake Valley, with the lowest level of grazing use, showed a winterfat age profile more skewed toward younger plants, although very old plants were also present. The age profile of the winterfat in Wah Wah Valley was the most similar to the age profile of winterfat in our sampling area. Both populations, having a long early history of abusive grazing, contained few young individuals and many very old plants.

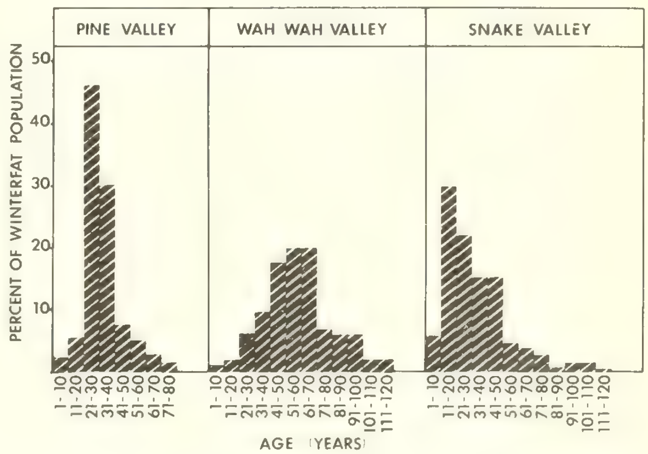

Figure 5.--Age distribution of winterfat populations in Pine, Wah Wah, and Snake Valleys, Utah. After Stewart, Cottam, and Hutchings (1940).

What changes in the study area have occurred during the past three decades which may have affected winterfat recruiting? The annual precipitation in the area has not been unusually low, high, or odd-timed (USDI, BLM 1979). Winterfat, in fact, may be favored over Atriplex during times of prolonged drought (Holmgren and Hutchings 1972). The 14-year drought which ended in 1934 (Pechanec and others 1937) did not curtail recruiting of winterfat in the sampling area, as the age profile of the population indicates.

[3] Lee Sharp, personal communication; 1983.

Recruiting for both species, however, is probably rather sporadic in this variable climate. A good year for seedling production occurs perhaps only once or twice a decade.[4] A recent (1955 to present) development[5] which may have had an effect is the placement of stock watering tanks in the Birds of Prey Study Area. This has allowed higher levels of grazing at dry times of the year (late spring and fall). Timing of grazing may be as important to winterfat as grazing intensity (Holmgren and Hutchings 1972).

It is not known whether Nuttall saltbush dominated some mosaic alternes in the Birds of Prey Study Area during presettlement times. Nuttall saltbush alternes may have been present then, but were unrecorded. Possibly, however, Nuttall saltbush replaced winterfat in a portion of the big sagebrush-winterfat mosaic quite rapidly many decades ago when winterfat was injured by abusive grazing. Nuttall saltbush may have always been present in the winterfat alternes in low numbers. That Nuttall saltbush was a part of winterfat communities is supported by the fact that we found saltbush individuals scattered throughout winterfat alternes, and that these saltbush (on winterfat sampling lines 1W, 2W, and 3W) included plants older than the mean ages of saltbush in the saltbush alternes.

Further study of these mosaic communities would be rewarding. Comparisons of soil carbon isotope ratios in alternes of each species, such as those done in Utah by Dzurek (1980) (in a winterfat-shadscale ecotone) might be very useful in understanding the stability and tracing the vegetation history of these alternes. Lack of recruiting by both species, especially winterfat, should be of special concern to users and managers of the area.

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FLAVONOID AGLYCONES OF DIPLOID AND POLYPLOID ATRIPLEX CONFERTIFOLIA

Stewart C. Sanderson and Howard C. Stutz

ABSTRACT: Although diploids and polyploids (4n, 6n, 8n, 10n) of *Atriplex confertifolia* (Torr. & Frem.) S. Wats. are morphologically quite similar, they differ in some of their flavonoid constituents. All have the 6-H flavonols isorhamnetin and quercetin but only polyploids contain the 6-methoxy flavonols spinacetin and patuletin. Consequently flavonoid content is useful in distinguishing diploids from polyploids. Because of the morphological resemblance between ploidy levels and because of a lack of suitable alternative parents it is believed that the polyploid races of *A. confertifolia* are autoploids. The presence of unique flavonols in polyploids is therefore probably caused by a change in genetic regulation incident to polyploidy, and may be the result of heightened production of compounds which in diploids are intermittently produced or are present only in small amounts. Because of the genetic redundancy of polyploids and consequent reduced effectiveness of natural selection, introgression of the genetic basis for this chemical difference from other species seems unlikely.

INTRODUCTION

Atriplex confertifolia (Torr. & Frem.) S. Wats. (shadscale), a spiny shrub species dominant over many areas of the western United States, consists of a series of chromosome races (2n, 4n, 6n, 8n, and 10n) (Stutz and Sanderson 1983). Only two populations of hexaploids and one population of decaploids have been found, but diploids, tetraploids, and octaploids are widespread. Diploids are restricted to more central and northern parts of the range and are usually in less xeric sites than those occupied by polyploids. Some of the existing variation in stature and other characteristics between different populations within a chromosome race may be due to plastic response to differences in moisture or other environmental factors but much of it appears to be genetic. The diploids and decaploids are generally larger than the tetraploids, hexaploids, and octoploids, but otherwise all of the chromosomal races are so similar that it seems unlikely that whole genomes of any other species are involved in their origin. *A. confertifolia* races are therefore likely autoploid rather than alloploid.

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METHODS

Flavonoids were isolated by column chromatography and identified using ultraviolet shift spectroscopy (Markham and Mabry 1975). Where helpful, comparison was made with standard compounds isolated from appropriate sources (spinacetin from spinach and 8-methoxylated and 6, 8-dimethoxylated compounds from lemon peel). Demethylation of these compounds was carried out by heating with pyridinium hydrobromide and a trace of water; the more labile compounds were demethylated under nitrogen.

Leaf samples of about 1/5 oz. from individual plants or from populations (leaves from five or more plants mixed together) were air dried and hydrolyzed with 1N HCl for 1 hour in a boiling water bath. Leaves were then drained, ground in a mortar, and the resulting slurry stirred with portions of diethyl ether. The ether was then decanted and the residue after evaporation was washed with a small amount of methanol. Maximal amounts of the resulting solution were spotted on half-sheets (28.5 x 46 cm) of Whatman 3mm chromatography paper; the amount spotted was adjusted to afford the best detectability of faint compounds while avoiding overloading.

Chromatograms were run the short direction in 15 percent acetic acid, overrun to about 2 times normal running time. Four sheets at a time were run the second (long) direction in acetic acid-water-benzene (96:4:100 v/v/v), in a (18 x 25 x 56 cm) non-preequilibrated chamber. To aid visualization and to retard decomposition of air-labile compounds, chromatograms were sprayed with 2 percent methanolic aluminum chloride. They were examined in long-wave ultraviolet light.

RESULTS

The 6-methoxy flavonols, spinacetin and patuletin, plus isorhamnetin and quercetin were found in leaves of the polyploid races of *A. confertifolia* (except 4n *A. confertifolia*

from Barstow). Only isorhamnetin and quercetin, plus traces of kaempferol, were detected in diploids (figs. 1, 2 and table 1). Certain of the additional Atriplex species which were examined had the same diploid-polyploid flavonoid distribution as A. confertiflora, but A. corrugata had a constant pattern regardless of ploidy.

DISCUSSION

Because secondary products such as polyphenols are typically produced only at certain times or in certain plant parts such as leaves, leaf glands, or stems, their synthesis may often be altered by mechanisms of internal genetic control. Expression of flavonoids has been found to be limited in tissue culture, possibly because under these conditions certain cell organelles or plant parts, and consequently certain chemical products, are not formed (Forrest 1969; Thorpe and others 1971). Polyploidy apparently may be sufficient to similarly upset such control mechanisms (Haskell 1968; Levy 1976; Murray and Williams 1976; Mears 1980; and Levin 1983). However, normally, chemical markers are identical in diploids and autotetraploids derived from them (Soltis and others 1983).

Since Atriplex confertifolia is known to hybridize freely with several other Atriplex species (Stutz, this volume), an alternative explanation for the chemical differences between diploid and polyploid races in the species might be that the capacity for unique flavonoid synthesis in the polyploids was introduced by hybridization. Diploids could have escaped receiving any 6-methoxylation genes because of a reduced tendency to hybridize, as compared to polyploids, and also because of a tendency for plants of a given ploidy level to exchange genes only with others of the same level. The closest relatives of A. confertifolia according to Hall and Clements (1923) are A. parryi S. Wats. and A. spinifera Macbr. But while hybridization of A. confertifolia with these two species may exist, it has not yet been reported, although populations of A. confertifolia within the region of sympatry with A. parryi appear to carry a hint of past hybridization with that species. However since none of the samples of A. spinifera which we have examined have shown any evidence of spinacetin nor patuletin, they do not appear to be likely candidates for the source of these compounds. A. corrugata S. Wats. and A. parryi do have the required compounds on the diploid level, and so perhaps they could have served as a source. However, extensive interspecific and interploid gene flow would have been required to achieve the apparent universal presence of chemical markers throughout both the numerous polyploid populations of A. confertifolia and also of other species with the same type of diploid-polyploid flavonoid distribution. Considering the genetic redundancy of polyploids, gene flow of that magnitude would have required a strong selective advantage, to say the least, but no advantage at all has yet become apparent.

It seems likely therefore, that the flavonol 6-methoxylating ability of polyploids is best explained on the basis of modified regulation of genes which, although in fact present in diploids, are not prominently expressed. The activity of such genes might be restricted to particular organs in diploids, or might be expressed only in unusual circumstances. Because "constant" selection over time would be required to preserve the functional integrity of the relevant genes from loss through mutation, it must be supposed that, when present, the 6-methoxylating ability does serve some useful purpose. Reported functions of flavonoids include formation of sunscreens, enzyme cofactors, enzyme inhibitors, precursors of toxic substance, contributors to pigmentation, and defense agents (McClure 1975). Perhaps increased information regarding function, as suggested by Zucker (1983) will make the present case more understandable.

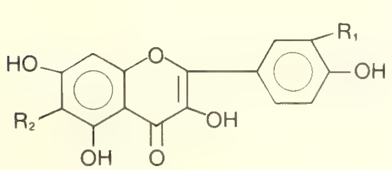

Figure 1.-- Flavonols of Atriplex confertifolia
spinacetin R_1 = OCH_3, R_2 = OCH_3,
patuletin R_1 = OH, R_2 = OCH_3
isorhamnetin R_1 = OCH_3, R_2 = H;
quercetin R_1 = OH, R_2 = H
kaempferol R_1 = R_2 = H

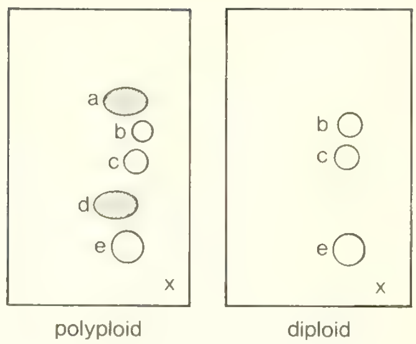

Figure 2.-- Paper chromatography of flavonoid aglycones of Atriplex confertifolia. Compounds shown are a. spinacetin, b. isorhamnetin, c. kaempferol, d. patuletin, and e. quercetin.

Table 1.-- Populations of Atriplex confertifolia examined by flavonoid chromatography.

Species	Ploidy	Location	Flavonoids 6-OMe	Flavonoids 6-H
A. confertifolia (Torr. & Frem.) S. Wats.	2N	Pocatello, Bannock Co., Idaho	0	+
	2N	Hardin, Big Horn Co., Montana	0	+
	2N	S end of Snake Range, White Pine Co., Nevada	0	+
	2N	Painted Hills, Wheeler Co., Oregon	0	+
	2N	Antelope Island, Davis Co., Utah	0	+
	2N	5 mi W of Fairfield, Utah Co., Utah	0	+
	2N	10 mi E of Fry Canyon, San Juan Co., Utah	0	+
	2N	Harley Dome, Grand Co., Utah	0	+
	2N	Horse Canyon turnoff, hwy US 6/50, Emery Co., Utah	0	+
	2N	Moore rd exit, hwy I-80, Emery Co., Utah	0	+
	2N	Alcova, Natrona Co., Wyoming	0	+
	2N	2 mi E. of Worland, Washakie Co., Wyoming	0	+
	4N	25 mi W of Barstow, San Bernadino Co., California	0	+
	4N	N end of Spring Valley, White Pine Co., Nevada	+	+
	4N	15 mi S of Wendover, Elko Co., Nevada	+	+
	4N	Cottonwood Creek, Kane Co., Utah	+	+
	4N	3 mi E of Faust, Tooele Co., Utah	+	+
	4N	3 mi E of Fry Canyon, San Juan Co., Utah	+	+
	4N	1 mi W of Horse Canyon turnoff, hwy US 6/50, Emery Co., Utah	+	+
	4N	5 mi N of Montezuma Creek, San Juan Co., Utah	+	+
	4N	Wellington, Carbon Co., Utah	+	+
	4N	Westwater Creek, Grand Co., Utah	+	+
	4N	2 mi N of Alcova, Natrona Co., Wyoming	+	+
	6N	16 mi E of Four Corners, Montezuma Co., Colorado	+	+
	6N	10 mi S of Cortez, Montezuma Co., Colorado	+	+
	6N	5 mi N of Green River in Grand Co., Utah	+	+
	8N	Barstow, San Bernardino Co., California	+	+
	8N	Boron, Kern Co., California	+	+
	8N	Newberry Springs, San Bernardino Co., California	+	+
	8N	Glendale, Clark Co., Nevada	+	+
	8N	20 mi S of Deseret, Millard Co., Utah	+	+
	8N	½ mi E of Faust, Tooele Co., Utah	+	+
	8N	10 mi S of Rowley, Tooele Co., Utah	+	+
	10N	1 mi S of Eskdale, Millard Co., Utah	+	+
	10N	15 mi E of Garrison, Millard Co., Utah	+	+
A. canescens[1] (Pursh) Nutt.	2N	Las Cruces, Dona Ana Co., New Mexico	0	+
	2N	Zia Pueblo turnoff, hwy NM 44, Sandoval Co., New Mexico	0	+
	2N	Little Sahara Dunes, Juab Co., Utah	0	+
	4N	Page, Coconino Co., Arizona	+	+
	4N	Carson City, Carson Co., Nevada	+	+
	4N	Montello, Elko Co., Nevada	+	+
	4N	Orem, Utah Co., Utah	+	+
A. corrugata S. Wats.	2N	5 mi E of Green River in Grand Co., Utah	+	+
	2N	15 mi N of Ouray, Uintah Co., Utah	+	+
	4N	Cainville, Wayne Co., Utah	+	+
	4N	Thompson, Grand Co., Utah	+	+
	4N	Wellington, Carbon Co., Utah	+	+

(con.)

Table 1.--(con.)

Species	Ploidy	Location	Flavonoids 6-OMe	6-H
A. cuneata	4N	Mack, Mesa Co., Colorado	+	+
A. Nels.	4N	Kirtland, San Juan Co., New Mexico	+	+
	4N	Cleveland, Emery Co., Utah	+	+
A. cuneata[2]	2N	15 mi NW of Maybell, Moffat Co., Colorado	0	+
ssp. introgressa	2N	Jensen, Uintah Co., Utah	0	+
C. Hanson	2N	5 mi N of Woodside, Emery Co., Utah	0	+
A. gardneri	2N	4 mi E of Point of Rocks, Sweetwater Co., Wyoming	0	+
(Moq.) Dietr.	2N	20 mi N of Rawlins, Carbon Co., Wyoming	0	+
	2N	Riner rd exit, hwy I-80. Sweetwater Co., Wyoming	0	+
	2N	8 mi N of Rocksprings, Sweetwater Co., Wyoming	0	+
	4N	Walden, Jackson Co., Colorado	+	+
	4N	Green River, Sweetwater Co., Wyoming	+	+
	4N	Rocksprings, Sweetwater Co., Wyoming	+	+
A. parryi[3]	2N	Newberry Springs, San Bernardino Co., California	tr	+
S. Wats.	2N	10 mi SW of Currant, Nye Co., Nevada	tr	+
	2N	2 mi S of Scotty's Junction, Nye Co., Nevada	tr	+
A. spinifera	4N	Boron, Kern Co., California	0	+
Macbr.	4N	Rosamond, Kern Co., California	0	+
	4N	Wasco, Kern Co., California	0	+

[1]A. canescens and allied species contain additional races at hexaploid and higher polyploid levels (in Mexico, the Mojave Desert and central Nevada) in addition to those races shown. Some of these resemble diploids in lacking 6-methoxyl flavonols, but differ from diploids in having an additional compound, the flavone tricin, whose distribution is under study.

[2]A. cuneata ssp. introgressa and A. gardneri produce, in addition to the compounds listed above, the 3-methyl ethers of isorhamnetin, quercetin and kaempferol, suggesting a phylogenetic relationship between these taxa.

[3]An additional 6-methoxylated compound is seen in small amounts in A. parryi and rarely on other species. It appears to be eupafolin (6-methoxy kaempferol).

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Section 2. Ecological Relationships

AUTECOLOGICAL STUDIES WITH ATRIPLEX TRIANGULARIS WILLDENOW

Irwin A. Ungar

ABSTRACT: Investigations were conducted to determine the influence of biotic and abiotic factors on the seed ecology, growth, and distribution of Atriplex triangularis Willdenow. Both intraspecific and interspecific forms of competition reduce the growth of A. triangularis. Seed germination and growth are strongly inhibited by salinity concentrations above 2 percent NaCl. Seed production is reduced under conditions of biotic or abiotic stress, because the number of seeds produced by plants is directly related to plant size. Seed polymorphism provides for nondormant large seeds and the dormant small seeds which contribute to a permanent seed bank.

INTRODUCTION

Atriplex triangularis Willdenow (Chenopodiaceae) is an herbaceous annual halophyte which is commonly found in both inland and coastal salt marsh habitats (Osmond and others 1980). Although A. triangularis is capable of growing in highly saline environments, it also grows well under less saline conditions (McMahon and Ungar 1978; Riehl and Ungar 1983). Other species of Atriplex have been reported to have optimal growth under conditions of low salinity (Black 1956, 1960; Gale and Poljakoff-Mayber 1970). A. triangularis appears to be very plastic in its response to environmental conditions, varying from dwarfed unbranched organisms which produce few seeds in highly saline habitats to multibranched plants that produce large number of seeds in less saline environments. Binet (1967) has reported similar phenotypic plasticity in the French coastal species Atriplex babingtonii Woods and related it to differences in exposure to tidal action.

Recently there have been several excellent reviews of the literature by Osmond and others (1980), Kelley and others (1982), and Sharma (1982) concerning the ecology of species within the genus Atriplex. These reviews show that certain aspects of the autecology of these species have not been examined in great detail. Although the plant-soil relationships have been well documented for the salt desert shrubs Atriplex confertifolia (Torr. and Frem.) Wats., A. nuttallii Wats., and A. corrugata Wats. (Flowers 1934; Gates and others 1956; Branson and others 1967, 1970, 1976; Breckle 1976), less data are available concerning the salt tolerance of A. triangularis.

The limitation of A. triangularis to certain portions of the salinity gradient indicates that some biotic and/or abiotic factors are acting to control its distribution. Several authors suggest that high soil salinity would greatly repress the growth of halophytes and limit their distribution (Clarke and Hannon 1971; Waisel 1972; Mahall and Park 1976; Ungar and others 1979). Another possibility is that competition with more- and less-salt-tolerant species plays an important role in determining the growth rate and actual distribution of halophytes in a variety of habitats (Szwarcbaum and Waisel 1973; Zedler 1977; Barbour 1978). Because a combination of biotic and abiotic factors probably limits the distribution of halophytes, each system should be studied using the paradigm of Clarke and Hannon (1971) to determine the precise nature of the effect these various environmental factors have on growth and distribution of plants.

Species of Atriplex often are found in saline soils (Flowers 1934; Branson and others 1976; Breckle 1976; McMahon and Ungar 1978; Osmond and others 1980). In the inland salt pans of Ohio, Na^+ and Cl^- are the main components of saline soils (Riehl and Ungar 1983). These ions compose about 90 percent of the total dissolved solids in these soils. High Na^+ and Cl^- ion concentrations are characteristic of salt marsh soils in Kansas, Oklahoma, and Nebraska (Ungar 1974), and are, of course, characteristic of coastal marsh soil conditions (Chapman 1974). Salts in saline soils of the more northern and western portions of North America have higher proportions of sulfates and carbonates of magnesium and calcium than those of the coastal and southern prairie marshes (Ungar 1974; Breckle 1976). Seasonal changes in the salt content of inland saline soils of Ohio are characterized by lower spring and winter soil salinities and higher summer soil salinities, especially in the surface soils (McMahon and Ungar 1978; McGraw and Ungar 1981; Riehl and Ungar 1982, 1983). Higher soil salinities during the summer months are due mainly to two factors: drought periods, and high air temperatures accelerate evaporation which concentrates salts in the surface soils.

The salt marsh at Rittman, Ohio, in which most of these studies of A. triangularis have been completed, is located adjacent to a salt mining operation of the Morton Salt Company. The salt flat environment has five main vegetation zones. In order of occurrence along a gradient of decreasing soil salinity these include: Pan Salicornia, Salicornia, Atriplex, Hordeum, and Meadow. The Pan Salicornia zone is characterized by scattered individuals of S. europaea and the absence of other flowering plants. The highest soil salinities are found in this zone of the marsh, with electrical conductivities of the soil solution averaging 75 mmhos cm^{-1} through the growing season.

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The *Salicornia* zone is characterized by high density populations of *S. europaea* L., but it is occasionally associated with *A. triangularis* and *Spergularia marina* (L.) Griesb. in the less saline portions at the upper margin of this zone. Soil salinities in the *Salicornia* zone reach a maximum of 85.5 mmhos cm^{-1} electrical conductivity during midsummer (averaging 49 mmhos cm^{-1} through the growing season).

The *Atriplex* zone is dominated by *A. triangularis*, but *Salicornia europaea*, *Spergularia marina* and *Hordeum jubatum* L. are associated with it. Soil salinity levels average 33 mmhos cm^{-1} electrical conductivity, reaching as high as 85 mmhos cm^{-1} at the limits of *A. triangularis* distribution. In the high salt *Atriplex* area, *A. triangularis* is mixed with *S. europaea*. In the low salt area it is chiefly associated with *Hordeum jubatum* and *Spergularia marina*. Plants growing in the low salt area are larger and more branched than those in the high salt habitats. Figure 1 illustrates the small transition zone containing *Atriplex* which occurred at the edge of the *Salicornia* zone in 1981 and 1982. During earlier measurements on this 20-quadrat transect in 1975, *A. triangularis* was found growing in quadrats 6 through 15 (Ungar and others 1979), but increased soil salinity concentrations since 1978 have limited its distribution to quadrats 16 through 20 which were formerly dominated by *Hordeum jubatum*.

The *Hordeum* zone is dominated by *H. jubatum*. Associated with this species are scattered individuals of *A. triangularis*, *Polygonum aviculare* L.,

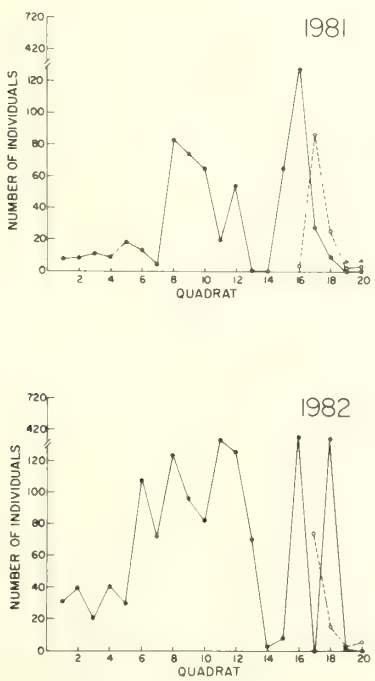


Figure 1.--Distribution of species in 1981 and 1982 along a salinity gradient at the Rittman, Ohio, salt marsh. Closed circles = *Salicornia europaea*. Open circles = *Atriplex triangularis*. Closed triangles = *Hordeum jubatum*.

Agropyron repens (L.) Beauv., *Convolvulus sepium* L., and *Poa compressa* L. Soils in this area reach a maximum soil salinity level of 15 mmhos cm^{-1} and average 9 mmhos cm^{-1} during the growing season.

The Meadow zone is composed of a mixture of old field species including *Hordeum jubatum*, *Dipsacus sylvestris* Huds., *Juncus tenuis* Willd., *Juncus effusus* L., *Cyperus esculentus* L., *Typha angustifolia* L., *Phalaris arundinaceae* L., *Solidago* spp., *Daucus carota* L., *Rumex crispus* L., *Agropyron repens* (L.) Beauv., *Erigeron philadelphicus* L., *Panicum clandestinum* L., and *Chenopodium glaucum* L. Soil salinity levels reach a maximum of 7 mmhos cm^{-1} electrical conductivity in this zone, averaging 3 mmhos cm^{-1}.

GROWTH-WATER POTENTIAL

Growth of *Atriplex triangularis* under field conditions is markedly affected by soil salinity conditions (table 1). Dry weight production under high salt conditions, averaging -3.0 MPa and ranging from -1.3 to -4.5 MPa, was only 3.5 percent of the production in low salt environments where the soil water potential averaged -0.9 MPa and ranged from -0.3 to -1.7 MPa through the growing season. A population of *A. triangularis* from one of the low salt habitats had high mortality, with few seed producing survivors, when it was inundated with highly saline water (-4.0 to -5.0 MPa) during September and October of the 1982 growing season. Black (1956), and Gale and others (1970) found a sharp reduction in dry weight production of other *Atriplex* species at salinity levels of -1.0 MPa and decreasing growth at more negative values.

Water status measurements of field plants, using a Wescor HR-33 dew point microvoltmeter equipped with a C-52 sample chamber, indicate that *A. triangularis* was capable of adjusting its water potential to that of the soil water potential. Data collected in 1979 show that in high salt environments (averaging -1.5 MPa) leaf osmotic potentials ranged from -2.4 to -4.7 MPa and leaf water potentials ranged from -1.7 to -4.1 MPa during the growing season when soil water potentials ranged from -0.7 to -2.9 MPa (table 2). Earlier investigations by Riehl and Ungar (1983) reported soil and plant water potentials more negative than -5.0 MPa in July, but in these locations *A. triangularis* plants did not survive to maturity. Water potential and osmotic potential measurements of *Atriplex* by Ungar (1977), Dejong (1979), and Richardson and McKell (1980) also showed that plants could adapt to media salinity levels. On a dry weight basis, approximately 15 percent of the shoot weight of plants growing in high salt environments and 5 percent of the shoot weight in low salt habitats can be attributed to inorganic ion accumulation. Other species of *Atriplex* have also been found to accumulate high concentrations of inorganic ions (Black 1960; Greenway and others 1966; Gale and others 1970; Sharma and others 1972; Breckle 1976; Storey and Wyn Jones 1979; Binet and Thammavong 1982).

Table 1.--Fresh weight and dry weight production of Atriplex triangularis plants growing in low salt and high salt environments.

	Low salt			High salt		
	Shoot	Root	Total	Shoot	Root	Total
Fresh weight (g)	12.280	0.297	12.577	0.700	0.014	0.714
± SD	3.612	0.125		0.273	0.004	
Dry weight (g)	2.435	0.112	2.547	0.084	0.005	0.089
± SD	0.605	0.045		0.032	0.002	
Shoot:root ratio (dry weight)		22:1			16:1	

Table 2.--Changes in soil water potential, and changes in osmotic potential (OP) and water potential (WP), of Atriplex triangularis leaves during the 1979 growing season. Data = MPa

	Soil		Leaf			
	Low salt	High salt	Low salt		High salt	
Date	WP	WP	WP	OP	WP	OP
31 March	0.6	0.7	[1]1.5	-	[1]1.7	-
30 April	1.1	1.6	1.6	1.9	3.3	3.6
26 May	0.4	0.7	1.1	1.5	2.0	2.4
27 June	1.9	2.9	3.3	3.6	3.3	4.0
30 August	0.9	1.3	2.4	2.7	2.9	3.5
27 September	0.5	1.6	2.2	2.4	4.1	4.7
28 October	1.1	1.6	2.0	2.9	3.0	3.6

[1]Cotyledon.

RESOURCE ALLOCATION

Harper (1977) reported that native annuals have reproductive efforts ranging from 15 to 30 percent of the total net resources allocated to plant organs, while in herbaceous perennial species reproductive effort accounts for 5 to 25 percent of the total. Few data are currently available regarding the allocation of resources to reproductive versus vegetative organs in the genus Atriplex (Osmond and others 1980; Kelley and others 1982; Sharma 1982). McMahon and Ungar (1978) reported that up to an average of 31 percent of the dry matter produced by field populations of A. triangularis was allocated to reproductive structures at the end of the growing season. There is an increase in relative allocation of dry matter to reproductive versus vegetative structures in these plants from July through September (table 3). Field data collected from saline environments in Ohio during 1980 and 1981 indicated values for reproductive effort of A. triangularis ranged from 25 to 37 percent of the total biomass production.[1] Plants in the high salt environments at the Rittman marsh in 1980 were dwarfed and they had fewer nodes than those plants growing in low salt habitats (table 4).

[1]Wertis and Ungar. Unpublished data, 1981.

Dry weight biomass data collected from plants of A. triangularis grown in the laboratory indicate that salinities up to 1 percent NaCl stimulated growth, while higher levels of salt stress were inhibitory (table 5). Resource allocation to vegetative structures remains fairly uniform at all salinities.

Seed production of plants from high salt environments was reduced to 33 percent of that in low salt habitats. Mean seed diameter and mean seed weight are lower in plants from less saline habitats. The small and large seeds collected from plants in the two zones did not have significantly different mean weights or mean diameters, but plants growing in low salt habitats were found to contain a greater proportion of small seeds.

The lowest resource allocation to seeds was in the 3.0 percent salinity treatment in which seeds only accounted for 7.8 percent of the total dry weight. At other salinity levels, seed weight accounted for from 11.0 to 12.3 percent of the total dry weight of plants (table 5). These results represent a fairly uniform resource allocation to vegetative and reproductive structures until salinity stress becomes limiting. At 3.0 percent NaCl the allocation to seeds is about 40 percent less than the optimal values and few viable seeds were produced. The number of seeds produced per plant varied with different levels of

Table 3,--Changes in resource allocation of Atriplex triangularis under field conditions during the growing season (from McMahon and Ungar 1978).

Month	Mean dry weight mg per plant^{-1}	Percentage of total		
		Root	Shoot	Reproductive
May	22.8	16.6	83.4	0.0
June	81.0	18.6	81.4	0.0
July	356.7	14.5	83.1	2.4
August	309.0	11.9	76.1	12.0
September	1071.8	11.5	57.5	31.0

Table 4.--Vegetative and reproductive characteristics of field populations of Atriplex triangularis growing in high salt and low salt environments.

Characteristic	High salt	Low salt
Plant height, cm $\pm$ SD	19.4 $\pm$ 2.5	33.9 $\pm$ 5.3
Nodes, No. $\pm$ SD	7.7 $\pm$ 1.4	15.4 $\pm$ 1.9
Seed number, $\pm$ SD	58.2 $\pm$ 15.7	185.0 $\pm$ 41.8
Seed diameter, mm $\pm$ SD	1.4 $\pm$ 0.05	1.2 $\pm$ 0.03
Seed weight, mg $\pm$ SD	1.0 $\pm$ 0.29	0.6 $\pm$ 0.15
Large seed	2.0 $\pm$ 0.04	2.0 $\pm$ 0.06
Small seed	0.5 $\pm$ 0.01	0.5 $\pm$ 0.01
Small:large seed ratio	6.1:1	63:1

Table 5.--Resource allocation of Atriplex triangularis plants grown under different salinity treatments.

NaCl %	Dry weight g. plant^{-1}	Percentage of total			
		Vegetative		Reproductive	
		Root	Shoot	Bract	Seed
0.0	1.78	29.8	51.7	6.2	12.3
0.5	2.45	25.3	53.1	10.6	11.0
1.0	2.05	24.4	52.2	12.2	11.2
2.0	1.22	20.5	51.6	15.6	12.3
3.0	0.51	27.5	52.9	11.8	7.8

salinity treatment (table 6). The largest number of seeds produced, a mean number of 541 seeds plant^{-1}, was observed in the 0.5 percent NaCl treated plants which also yielded the highest plant dry weight production.

A positive significant linear relationship exists between dry weight production and the number of seeds produced plant^{-1}, $Y = 24.52 + 224.52X$, $r^2 = 0.87$, $P<0.01$. Small plants produced fewer seeds than large plants and this relationship was most marked in the 3.0 percent NaCl treatment. The ratio of small to large seeds varied with salinity treatments, but remained fairly constant in salinity treatments ranging from 0.5 to 1.0 percent NaCl (table 6).

INTERSPECIFIC COMPETITION

Clarke and Hannon (1971), Szwarcbaum and Waisel (1973), Zedler (1977), and Ungar and others (1979) have indicated that interspecific competition was a significant factor affecting the distribution of halophytes. Competition studies indicated that some halophytes were better competitors in saline than freshwater conditions (Wilson 1967; Szwarcbaum and Waisel 1973; Gray and Scott 1977; Barbour 1978; Suehiro and Ogawa 1980). These data concerning the inability of halophytes to compete effectively with glycophytes explain why salt tolerant species such as Atriplex triangularis may not grow to maturity in low saline and non saline environments. Field investigations in

Table 6.--The effect of salinity on the number of seeds produced per Atriplex triangularis plant, and the ratio of small to large seeds.

NaCl	Number of seeds per plant^{-1}			Ratio
	Small	Large	Total	
0.0	361	87	448	4.4:1
0.5	366	175	541	2.1:1
1.0	311	152	462	2.0:1
2.0	235	162	397	1.5:1
3.0	71	2	73	35.5:1

native habitats are necessary to determine if species distributions are limited by salt stress or interspecific competition. Reciprocal transplants of species into different zones over an environmental gradient could provide additional evidence concerning the relative influence of biotic and abiotic factors on halophytic species distribution and growth (Clarke and Hannon 1971; Ungar and others 1979; Vince 1981).

Transplants of soil cores, averaging 2.5 in. (6 cm) in diameter and 4 in. (10 cm) in length, containing ten A. triangularis seedlings were made along two transects in May 1974. A total of five soil cores were transplanted into cleared and uncleared plots in each of the five vegetation zones. Survival was measured during July, August, and October 1974 (table 7). No A. triangularis plants survived in the pan zone containing scattered individuals of Salicornia europaea. This vegetation zone was subjected to the highest soil salinities, averaging greater than 40 mmhos cm^{-1} electrical conductivity throughout the growing season and reaching values as high as 145 mmhos cm^{-1} during the summer months. Transplants into the Salicornia zone also had low survival, averaging less than 5 percent in the four treatments, with no survivors in the cleared plots. High mortality could be attributed to the inability of A. triangularis to tolerate prolonged periods during the summer months with soil salinities averaging greater than 60 mmhos cm^{-1} electrical conductivity.

Survival in the other three zones ranged from 44 percent in the Atriplex zone to 61 percent in the Hordeum zone, with an intermediate value of 55 percent in the Meadow zone. Where plants survived in both cleared and uncleared plots, plants growing in the cleared plots had higher shoot and root dry weight production (fig. 2). Maximal biomass production for A. triangularis was obtained from cleared plots in the Meadow zone. A reduction in growth of A. triangularis plants in uncleared plots in the two less saline zones, Hordeum and Meadow, indicates that interspecific competition was important in determining both the level of plant production and the species distribution along this salinity gradient. Interspecific competion results in reduced growth and limits the root system of A. triangularis to the surface 2 inches (5 cm) of soil. This increases the chances of moisture stress injury in

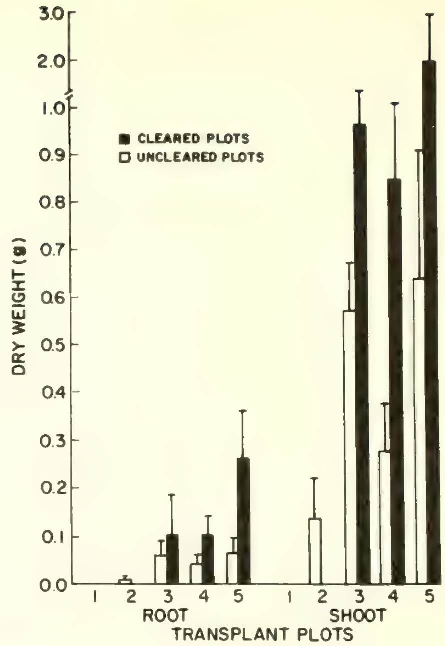


Figure 2.--Mean dry weight production of Atriplex triangularis plants transplanted into cleared and uncleared plots in five vegetation zones. 1. Pan Salicornia, 2. Salicornia, 3. Atriplex, 4. Hordeum, 5. Meadow.

the less saline zones and also increases salt stress injury in the highly saline zones.

INTRASPECIFIC COMPETITION VERSUS ABIOTIC STRESS

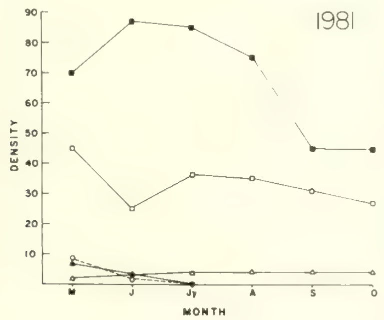
Both the size and survival of plants in many natural systems are considered to be controlled by density dependent factors (White and Harper 1970; Bazzaz and Harper 1976; Watkinson 1982). In studies with halophytes, Weaver (1918), Wendelberger (1950), Ungar and others (1979), and Jefferies and others (1981) concluded that mortality of plants is primarily due to abiotic factors. In their studies with Salicornia europaea populations in coastal and inland saline environments, Jefferies and others (1981), and Riehl and Ungar (1982) found that plant size and production were influenced by the initial densities of these populations. Further studies are needed to determine if there is a synergistic relationship between density dependent and density independent factors which affect growth and survival in saline environments.

Field transplant studies indicate that A. triangularis plants transferred back into the Atriplex zone had a 42 percent decrease in yield in uncleared plots compared to cleared plots (fig. 2). Data collected from thinning experiments in the field also indicate that biomass production is density dependent. Densities of 1, 10, 25, and 100 plants per 15.5 in.^{2} (100 cm^2) quadrat yielded dry weights of 188, 174, 93, and 60 mg plant^{-1} in each case respectively, indicating that high field densities can account for up to 70 percent reduction in yield of A. triangularis plants in pure stands.

Table 7.--Mean survival of 50 Atriplex triangularis plants in each zone on two transects along a salinity gradient. Ten plants were transplanted in each of five cores at each location in May. Mean ± S.E

		Transect I		Transect II	
Zone	Month	Cleared	Uncleared	Cleared	Uncleared
Salt Fan	July	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
	August	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
	October	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0
Salicornia	July	0.0 ± 0.0	2.0 ± 0.4	0.0 ± 0.0	2.0 ± 1.0
	August	0.0 ± 0.0	1.6 ± 0.2	0.0 ± 0.0	1.0 ± 0.5
	October	0.0 ± 0.0	0.6 ± 0.4	0.0 ± 0.0	1.0 ± 0.5
Atriplex	July	3.6 ± 0.9	4.4 ± 0.7	4.8 ± 1.2	9.4 ± 0.6
	August	3.6 ± 0.9	4.4 ± 0.7	3.4 ± 0.6	7.4 ± 0.9
	October	3.2 ± 0.5	4.4 ± 0.7	2.6 ± 0.8	7.4 ± 0.9
Hordeum	July	4.4 ± 0.9	6.4 ± 1.3	9.2 ± 0.4	9.0 ± 1.0
	August	3.2 ± 0.7	6.2 ± 1.2	8.6 ± 0.7	7.6 ± 1.4
	October	3.2 ± 0.7	6.2 ± 1.2	7.2 ± 1.3	7.6 ± 1.4
Meadow	July	5.0 ± 1.5	7.0 ± 1.3	5.2 ± 1.5	5.4 ± 1.5
	August	4.6 ± 1.2	6.2 ± 1.2	4.2 ± 1.6	5.4 ± 1.5
	October	4.0 ± 1.3	6.2 ± 1.2	4.2 ± 1.6	5.4 ± 1.5

Mortality of A. triangularis plants in different portions of a salinity gradient was found to occur at different times during the 1981 and 1982 growing seasons (fig. 3). In 1981, conditions were stable in terms of precipitation and soil salinity and only in the less saline sites 1 and 2 was mortality high early in the growing season. In 1982,



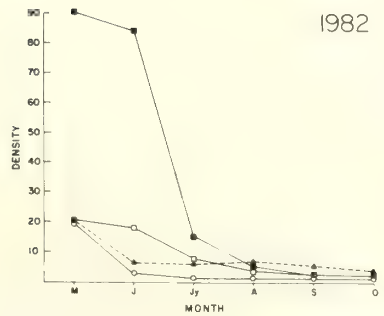


Figure 3.--Survival of Atriplex triangularis in 100 cm^2 quadrats during the 1981 and 1982 growing seasons. Quadrat 16-20 of Figure 1. 16 = open triangle, 17 = closed square, 18 = open square, 19 = open circle, and 20 = closed triangle.

the period of highest mortality was between the May and June measurements in the less saline sites and between the June and July measurements in the more saline sites 3 and 4 (fig. 3). The latter mortality was probably due to an increase in soil water potentials from -3.0 MPa to -5.9 MPa during this period in the high salt Atriplex zone. Mortality in the low salt zones was probably due to drought stress and the increased salinities induced by low precipitation during the early part of the growing season, when precipitation was 65 percent less than normal. Osmond and others (1980) found that plant establishment was related to the quantity and periodicity of precipitation. High summer precipitation favored establishment of A. vesicaria Heward and A. stipitata Benth.

Keddy (1981) has suggested a technique for determining whether differences in survivorship for populations of a species are due to density dependent or density independent factors. Applying this procedure in an attempt to interpret changes in field densities of A. triangularis indicates that the chief factors determining survival of plants are environmental. Survival was not closely related to maximal plant density as would be expected if density dependent factors were significant (fig. 4). Data were collected from 16 $in.^2$ (100 cm^2) quadrats over a four year period. The linear regression Y = 26.0771-0.1196 X, has a regression coefficient which is not significantly different from 0 ($P<0.4$). The coefficient of determination, r^2 = 0.0217, explains only a very small portion of the variation in survival in relation to initial plant density. High plant density causes a decrease in plant size (Riehl and Ungar 1982, 1983). Small shallow root systems produced by smaller plants are more susceptible to salinity or drought stress which is most severe in the surface soils.

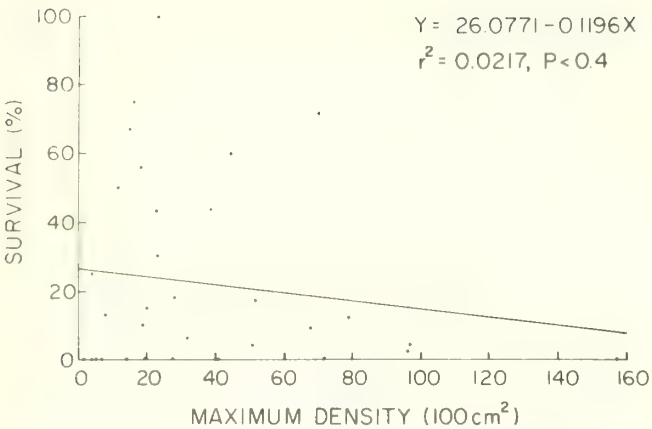


Figure 4.--The relationship between peak plant densities in 100 cm^2 quadrats and survival in Atriplex triangularis populations.

Very high salt stress appears to cause mortality at all plant densities.

SEED DIMORPHISM

Some plant species which grow in saline environments have developed seed dimorphism or polymorphism (Beadle 1952; Salisbury 1958; Konig 1960; Dalby 1962; Sterk 1969a,b; Drysdale 1973; Grouzis and others 1976; Ungar 1979, 1982). Seed polymorphism is a significant advantage to species growing in variable environments, because it provides alternate temporal and spatial germination situations. If there was only a single synchronized germination period in these highly variable environments and no seed reserve was available, an entire population of plants could be eliminated by increased salt stress during the growing season. We found that seeds of A. triangularis have an extended germination period, lasting from February to June, with some germination occurring even in late fall.[1] This pattern is most likely related to both the difference in physiological responses of dimorphic seeds and fluctuations in soil salinity during the growing season which limit the periods when seeds can germinate.

The presence of seed dimorphism in the genus Atriplex has been described for a number of species (Hall and Clements 1923; Beadle 1952; Frankton and Bassett 1968, 1970; Ungar 1971; Taschereau 1972). Nobs and Hagar (1974) found that large seeds of A. hortensis L. are produced earlier from flowers without a perianth but with bracteoles surrounding the fruit, while small seeds are produced later from flowers with a perianth but without bracteoles. Both large and small seeds of A. triangularis have bracteoles surrounding them when the fruit is mature (Ungar 1971). Beadle (1952) found that the ratio of small black to large brown seeds was variable in A. semibaccata F. Muell and A. inflata R. Br., ranging from 10:1 to 1.3:1 in the former and from 6:1 to 1:2.5 in the latter species. Drysdale (1973) reported that seed distribution in A. triangularis was log-normal, with a ratio of small to large seeds from 3:1 to 30:1, averaging 16:1 for the 46 plants observed. Further studies with A. triangularis under field and laboratory conditions indicate that plant size affects both the number of seeds produced plant^{-1} and the ratio of small to large seeds (table 4).

Collections of seeds from A. triangularis plants in October, 1980, indicate a statistically significant relationship (P<0.001) between seed weight and seed size. The linear regression curves for plants in both high and low salt environments are similar: $Y = 1.70 + 1.87 X$ (r^2 = 0.93) for high salt, and $Y = 1.78 + 1.83 X$ (r^2 = 0.92) for low salt habitats. Figure 5 illustrates the differences in frequency of distribution of seeds in seed size classes of plants in both high salt and low salt environments. Plants in high salt environments had a greater number of seeds in the larger diameter size classes than did plants from low salt habitats. Osmond and others (1980) reported that the seed coat of large brown seeds of A. hortensis is more permeable to water because it has an outer layer of thin walled cells, while the small black seeds which have a less permeable seed coat have an outer layer of cylindrical sclereids. Water uptake by large brown seeds was more rapid than by the small black seeds (Nobs and Hagar 1974; Osmond and others 1980). A 0.5 M NaCl treatment limited water uptake to less than 50 percent of the distilled water control.

SEED BANK

The significance of seed banks in determining the establishment of plant communities on saline soils is not well understood. A survey of seed reserves in nonsaline soils from ten contrasting environments containing herbaceous vegetation indicated a general lack of correspondence between the flora of any single area and the species composition of its seed bank (Thompson and Grime 1979). Van der Valk and Davis (1976, 1978) and Keddy and Reznicek

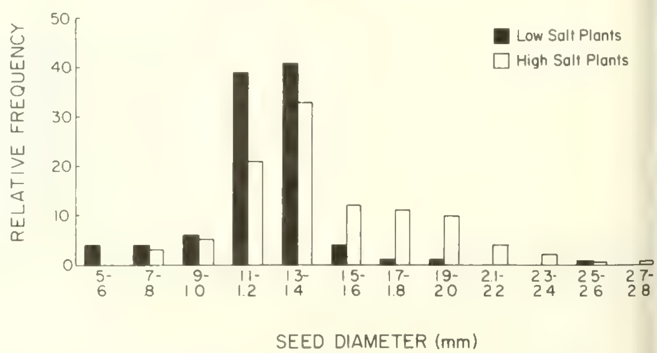


Figure 5.--Frequency of seeds in various size classes from Atriplex triangularis plants collected in low salt and high salt habitats.

[1] Ungar and Khan. Unpublished data, 1981.

(1982) concluded that the species composition of seed banks determined the nature of hydrarch succession in freshwater marshes. They found that seeds of all marsh species were dispersed into all of the vegetation zones. In contrast to these results, Leck and Graveline (1979) observed a correlation between the floral composition of a freshwater marsh and the makeup of its buried seed populations. They concluded that the seed bank was a good predictor of the plant communities in this New Jersey freshwater marsh. The quantitative nature of the seed bank also appears to vary from one year to the next. Young and others (1980) reported that seed banks had up to 300,000 seeds 10.8 ft.$^{-2}$ (m^{-2}) in wet years and 62,000 seeds 10.8 ft.$^{-2}$ (m^{-2}) during dry years in annual grssslands of California.

Milton (1939) found some variability in the relationship between the seed reserves in the soil and the actual species composition of halophyte communities. The seed bank of weed species growing at the margin of the salt marsh was larger than the actual presence of plants in marsh communities indicated. Several highly salt tolerant species were under-represented in the seed bank of these zonal saline communities. Jefferies and others (1981) in studies of Salicornia populations in coastal salt marshes reported that a persistent seed bank did not occur. Ungar and Riehl (1980) found that the three dominant halophytes along different portions of a salinity gradient, Hordeum jubatum, Atriplex triangularis, and Salicornia europaea were present in the seed banks of all zones. A glycophyte, Juncus tenuis, was the dominant in seed banks of spring collections from the Hordeum and Atriplex zones, even though no seedlings or mature individuals of this species were found growing in saline environments. The presence of these species with differing salt tolerance in all zones indicates that soil salinity is the primary factor controlling the distribution of plants along this gradient and that the species composition of these halophyte communities can change rapidly with changing soil conditions.

Atriplex triangularis seeds are polymorphic in size, producing a log normal distribution with more seeds in the small seed size classes .4 to .6 in. (1.0 to 1.5 mm) and fewer seeds in the large seed size classes .64 to 1.0 in. (1.6 to 2.6 mm) (Drysdale 1973). Soils were sifted through a 35 mesh, .2 in. (0.5 mm diameter) sieve to estimate the number of seeds in the soil. After seed fall in December there was an estimated 108,280 A. triangularis seeds 10.8 ft.$^{-2}$ (m^{-2}) in the seed bank, based on direct counts from soil samples (table 8). Following the normal February through May germination period, the surface soils (0 to 2 cm) were found to contain a mean number of 27,861 seeds 10.8 ft.$^{-2}$ (m^{-2}) in the seed bank from samples taken monthly from June to September 1981. Germinability of seeds collected from these monthly samples was high, averaging 76 percent throughout the year. The December and January collections containing a high proportion of fresh 1981 seeds averaged 73 percent germination, while seeds from the remaining months had an average germinability of 83 percent. Even after the normal germination period, seeds collected in soil samples from June through November had 88 percent germination, indicating that seed viability remains high throughout the year. Roberts and Neilson (1980) found that Atriplex patula L. seeds could remain buried in soils for at least 5 years without losing their viability.

Table 8.--Mean number of A. triangularis seeds m^{-2} in monthly seed banks, 1981.

Month	Small seed	Large seed	Total
April	38,208	0	38,208
May	41,401	0	41,401
June	28,656	0	28,656
July	28,656	0	28,656
August	25,478	0	25,478
September	28,656	0	28,656
October	35,032	637	35,669
November	35,032	3,185	38,217
December	95,541	12,739	108,280

A study of seasonal change in the proportion of large and small seeds in the seed bank produced by A. triangularis during 1981 showed that no large seeds were stored in the soil from April to September (table 8). The number of large seeds in the surface soil increased from 637 to 12,379 seeds 10.8 ft.$^{-2}$ (m^{-2}) during the period of seed rain from October through December. Large seeds germinated early in the growing season and were not part of the permanent seed bank. These large seeds would be classified as a Type II transient seed bank (Thompson and Grime 1979) since they are produced in the fall and remain in the seed bank only over winter. The small seeds of A. triangularis provide a Type IV permanent seed bank in which seeds that are produced in the fall ordinarily do not germinate until the following spring and persist in the soil for more than one growing season. Beadle (1952) found that perennial species of Atriplex which produced only large brown seeds were being replaced by annuals that produced both seed types. He hypothesized that large brown seeds were short-lived while the small black seeds probably accumulated in the soil as a seed reserve until the testas become permeable. Our data with A. triangularis support this hypothesis since the small black seeds were the only size class to form a permanent seed bank.

GERMINATION

The effect of salinity stress on the physiology and ecology of germination of halophyte seeds has been reviewed recently by Ungar (1978, 1982). Two differences in the behavior of halophytes are apparent in comparison to glycophytes. First, seeds of salt tolerant plants are able to germinate at higher salinities than intolerant organisms, but they still respond with reduced final germination percentages and with delays in seed germination when their tolerance limits are

approached. Second, unlike salt intolerant species, seeds of many halophytic species are capable of remaining dormant under hypersaline conditions and then germinating when salinity levels are reduced.

Temperature and salinity interact in their effects on seed germination. Ward (1967) found that seeds of A. hastata L. s. sp. novae zelandiae Aellen were dormant, but that they responded to a cold pretreatment. Germination rates of up to 95 percent were obtained in salinities up to 1 percent NaCl. No germination was found at salinities of 2, 3, or 4 percent NaCl. Gustafsson (1973) concluded that seeds of A. triangularis lost their viability in storage at 15° C and 18° C, because he obtained only from 6 to 8 percent germination. We have found that A. triangularis seeds remain dormant at constant temperatures (10° C to 25° C). Low germination percentages of laboratory seeds may be due to some induced dormancy (Khan and Ungar, unpublished data). Gustafsson (1973) found that seeds stored outdoors averaged 70 percent germination. Scandinavian seed sources were able to withstand salinities of 3 and 6 percent total salts and then germinate at levels equal to those of seeds not exposed to salt stress (Gustafsson 1973). Seeds of A. vesicaria and A. nummularia Lindl. were inhibited by increments of NaCl ranging from -0.2 MPa to -2.2 MPa and a delay in germination was observed at the higher salinities (Sharma 1973).

There is some question concerning the significance of bracteoles in determining the germination behavior of Atriplex species (Beadle 1952; Kadman-Zahavi 1953; Koller 1957; Binet 1965; Ward 1967; Sankhary and Barbour 1972; Billard and Binet 1975; Osmond and others 1980). Beadle (1952) concluded that chloride accumulation in the bracteoles was the cause of germination inhibition. He found that the levels of chloride, reported as NaCl equivalents, in the bracteoles of five Australian species of Atriplex ranged from 0.44 M to 0.90 M NaCl. The germination of seeds in unsoaked fruits that were enclosed in bracteoles was reduced by 57 percent in A. vesicaria, 54 percent in A. inflata and 94 percent in A. spongiosa F. Muell. Others, including Kadman-Zahavi (1953), and Koller (1957), felt that Cl^- was not the cause of inhibition, but that some other unknown water soluble inhibitor was present in the bracts. Osmond and others (1980) hypothesized that several inches of precipitation would leach salt from the bracteoles and then permit germination. Ward (1967) found that seeds of A. hastata subsp. novae zealandieae were shed from bracteoles prior to germination. She suggested that the chief function of bracteoles was to enhance dispersal by providing greater surface area to facilitate floating. In A. triangularis the bracteoles may serve both to disperse seeds and prevent germination during late fall, but they are not an inhibitory factor during the normal spring germination period because the bracteoles are completely decomposed by this time. Another possible function of bracteoles, suggested by Cresswell and Grime (1981) is to induce a secondary dormancy in seeds through the phytochrome system, because their chlorophyll increases the ratio of far red to red illumination reaching the seeds.

Seeds of A. triangularis were collected from plants growing in high salt and low salt environments to determine if the salinity to which parent plants were exposed had an influence on seed germination. Seeds were obtained from plants growing on a salt pan at Rittman, Ohio, in October 1980, and germination studies were initiated in June 1982. Four 25 seed replicates were used for each experimental condition. Petri dishes containing small black seeds were placed in an incubator with a 12 h photoperiod, a 5° C night temperature, and a 25° C day temperature. In comparison to treatments ranging from 0 to 1 percent NaCl, a significant decrease in germination was observed in the 2 percent NaCl treatment from both of the seed sources. An even sharper decline in germination was found in the 3.0 percent NaCl treatment (table 9). High recovery germination percentages, equivalent to those of the original germination values in distilled water, were obtained when seeds originally germinated in 2, 3, and 4 percent NaCl were returned to distilled water. No significant differences were found in the germination responses of seeds from the two different seed sources when germinated at salinities ranging from 0 to 3 percent NaCl. Ignaciuk and Lee (1980) found that germination of A. glabriuscula Edmondst. and A. laciniata L. was not inhibited by salinities of 4 and 5 percent NaCl upon return to distilled water (Zid and Boukhris 1977). A second experiment with seeds from laboratory grown plants indicated, as in the case of the field plants, that the conditions in which parent plants were grown (nutrient solution plus 0 to 2 percent NaCl) had no effect on the salt tolerance of their seeds.

To determine if media salinity influences the salt content of seed, a measurement was made of the ionic content of seeds produced under different growth conditions. Salt contents of seeds were estimated from specific conductance measurements of aqueous extracts of dry seed. Potassium and sodium ion content was determined by flame emission with a Perkin-Elmer model 360 atomic absorption spectrophotometer. Chloride ion content was measured with a Beckman chloride specific ion electrode. Seeds of field grown plants had an average total salt content of 2.1 percent from the high salt environment and 1.7 percent total salts

Table 9.--Percentage germination of small black seeds of Atriplex triangularis from plants originally growing in high salt and low salt environments.

	NaCl (%)				
	0.0	0.5	1.0	2.0	3.0
High salt	99	92	86	52	0
Low salt	100	99	96	66	0

from the low salt environment. Seeds of laboratory grown plants contained 1 percent total salts in the nutrient solution control and averaged 2.3 percent in seeds from the 2.0 percent NaCl growth treatment (table 10). Plants evidently can control the amount of Na^+ and Cl^- transported to seeds since these elements are maintained at a lower concentration in the seeds than in shoots. Potassium ion content remained relatively constant in seeds from all treatments, while Na^+ and Cl^- tended to increase with increasing salt increments (table 10). Considering the fact that shoot ionic content reached 5.0 percent total salts in the low salt plants and 15.0 percent in the high salt plants, there is a definite inhibition of Na^+ and Cl^- ion transfer to seeds. Poulin and others (1978) found that Na^+ concentrations in seeds of Salicornia europaea collected from saline environments averaged 0.77 percent of the dry weight compared to from 8.0 to 14.8 percent Na^+ in plants at later stages of development. Seeds of Cakile maritima Scop. were found to have a Na^+ content of 0.02 percent and a chloride content of 0.07 percent compared to leaf Cl^- contents of 14.1 percent and Na^+ concentrations of 6.8 percent (Hocking 1982).

These data indicate that halophytes control the transport of ions to seeds, where the ionic content is generally lower than in other plant organs, and in this manner avoid injury from osmotic stress or specific ion-induced stress during the period of embryonic development.

SUMMARY

1. Soil water potentials averaging -1.5 MPa (about 2.0 percent total salts) and lower caused a sharp reduction in growth of both root and shoot systems of Atriplex triangularis. Plants could survive under hypersaline conditions by adjusting their water potential to that of the marsh soils, but soil water potentials between -2.0 and -5.0 MPa were responsible for high mortality.

Table 10.--Percentage of total ionic content of Atriplex triangularis seeds from both field and laboratory grown plants.

	Plant Origin					
	Laboratory				Field	
	Salt Content					
	0.0	0.5	1.0	2.0	1.0	2.7
Na^+	0.2	0.3	0.3	0.5	0.6	0.7
K^+	0.6	0.6	0.6	0.6	0.5	0.7
Cl^-	0.1	0.3	0.2	0.4	0.5	0.7
Total salts[1]	1.0	1.7	1.6	2.3	1.7	2.1

[1]Total salt content estimated from electrical conductivity measurements.

2. Field plants collected at the end of the growing season were found to have allocated from 25 to 37 percent of their biomass production to reproductive structures. A significant linear relationship, $r^2 = 0.87$, was determined between the dry weight production of plants and the number of seeds produced per individual plant. Factors such as high soil salinity, drought, and competition that reduce plant size were responsible for a corresponding reduction in seed production.

3. Transplants of plants into cleared and uncleared plots established in different vegetation zones indicate, by their growth responses, that interspecific competition caused a reduction in both root and shoot yields of A. triangularis. High soil salinities were inhibitory to both the establishment and growth of plants in the Pan Salicornia and Salicornia zones.

4. Thinning experiments under field conditions confirmed that the dry weight production of plants was closely correlated to initial plant densities. Biomass production of individual plants also influenced seed production; larger plants produced greater numbers of seeds than smaller plants.

5. Seed dimorphism in A. triangularis is an important factor affecting the time of seed germination, seed dispersal, and long term storage of seed in the seed bank. Small black seeds in this species are more dormant and form a permanent Type IV seed bank. Large brown seeds all germinate in the spring, and produce only a transient Type II seed reserve.

6. Seed germination was inhibited at salinity levels above 1 percent NaCl. No direct relationship could be ascertained between the germination response of seeds at any salinity level and salinity conditions of parent plants in both the field and laboratory.

7. The ionic content of seeds varied from that of nutrient solution controls containing 1 percent salts to that of laboratory grown plants at 2 percent NaCl + nutrients which had a total of 2.3 percent total salts. Similar values were obtained from high salt environments in the field where seeds had a total salt content of 2.1 percent. Increases in the total ionic content of seeds were mainly due to Na^+ and Cl^- ion accumulation, but these values were much lower than the 15 to 20 percent total ion content found in shoots.

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NATURAL GROWTH OF ATRIPLEX SUCKLEYI ((Torrey) Rydb.) ON BENTONITE MINE SPOILS IN SOUTHEASTERN MONTANA

Carolyn Hull Sieg, Daniel W. Uresk, and Richard M. Hansen

ABSTRACT: Rillscale (Atriplex suckleyi (Torrey) Rydb.) was the most common and productive plant on bentonite mine spoils, comprising between 40 and 94 percent of the total plant canopy cover and standing crop on the mine spoils; yet, it was uncommon on the unmined sagebrush-grass sites. The success of rillscale on the mine spoils was attributed to its adaptation to the climatic and edaphic conditions of the area, an adequate seed source, and the absence (or near absence) of competing vegetation. Soil compaction, high sodium concentrations, and acidic soils limited growth of rillscale on some mine sites.

INTRODUCTION

Rillscale (Atriplex suckleyi (Torrey) Rydb.) is an annual chenopodiaceous plant limited to the Great Plains of North America (McNeill and others 1979). It occurs in Alberta and Saskatchewan, Canada, and in Montana, Wyoming, North Dakota, South Dakota, and Nebraska in the United States (Frankton and Bassett 1970). Also known as scurfless saltbush, and previously named A. dioica (Nutt.) Macbride (Frankton and Bassett 1970), rillscale is limited to alkaline or badland sites (Hitchcock and Cronquist 1973), and is a common plant on bentonite mine spoils in Montana, Wyoming, and South Dakota. This study was designed to sample the plant canopy cover and standing crop of rillscale on bentonite mine spoils and sagebrush-grass rangeland in southeastern Montana, and to identify soil and other environmental characteristics which limit its establishment.

STUDY AREA

This study was conducted in extreme southeastern Montana, approximately 6 miles (9 km) west of the town of Alzada. The study area was on a dense clay-clayey-saline upland range site complex, as defined by Ross and Hunter (1976), at an elevation of approximately 3,300 to 3,600 ft (1000-1100 m). Annual average precipitation is 15 inches (37 cm), most of which falls between May and July (U.S. Department of Transportation, National Oceanic and Atmospheric Administration 1976). In 1979 and 1980, 10 and 14 inches (26 and 35 cm) of precipitation fell, respectively. The May to July precipitation for 1979 was 6 inches (15 cm), while only 4 inches (11 cm) fell during this period in 1980. Vegetation consists mainly of big sagebrush (Artemisia tridentata Nutt.) with an understory of western wheatgrass (Agropyron smithii Rydb.), blue grama (Bouteloua gracilis (H.B.K.) Steud.), and buffalograss (Buchloe dactyloides (Nutt.) Engelm.). Vegetation on bentonite mine spoils in the study area is dominated by rillscale (Sieg and others 1983).

METHODS

Twelve study sites were selected: ten on bentonite mine spoils resulting from mining activities between 1952 and 1978, and two on adjacent, unmined rangeland. The study sites were classified into four types: (1) old mine spoils; (2) reclaimed spoils; (3) semireclaimed spoils; and (4) sagebrush-grass rangelands. Five sites were established on old spoils (predating reclamation laws), which were 12 to 28 years old, steep, and nearly devoid of vegetation. Three sites were established on 5- to 12-year-old reclaimed spoils, which had been recontoured, spread with topsoil and seeded with a mixture of wheatgrasses (Agropyron spp.) and yellow sweetclover (Melilotus officinalis(L.) Lam.). Two sites were established on semireclaimed spoil piles, which were the result of mining the previous fall. One of the semireclaimed spoils was seeded with wheatgrasses and yellow sweetclover during the fall of the first year of the study. The steep grade of the other pile prevented seeding. Two sites were established on gently undulating unmined sagebrush-grass rangeland. All sites were accessible to sheep and cattle.

Plant canopy cover and standing crop were sampled on the 12 sites on a regular basis for 2 years. Plant canopy cover was estimated in June, July, and August each year in 150, 1.1-ft^2 (0.1-m^2) quadrats, spaced at 3.3-ft (1-m) intervals, along three permanent 164-ft (50-m) transects on each site (Daubenmire 1959). Canopy cover was visually estimated by seven cover classes: 0 = less than 1 percent cover, 1 = 1 to 5 percent, 2 = 5 to 25 percent, 3 = 25 to 50 percent,

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4 = 50 to 75 percent, 5 = 75 to 95 percent, and 6 = 95 to 100 percent cover.

Plant standing crop was estimated by harvesting plants at ground level annually, at peak production (late July), on all sites. At each site, plants were clipped in ten 8-inch X 20-inch (20-cm X 50-cm) quadrats, on each of three permanent transects, were ovendried in the laboratory at 140° F (60° C) for 48 hours, and were weighed.

Twenty soil samples were taken on each site during the second year, to a depth of 4 inches (10 cm), with a 2-inch (5-cm) soil probe mounted on a drill truck. A grid pattern with 49-ft (15-m) spacing was used to distribute the samples throughout the sites. Four composite subsamples were analyzed from each site: two from the first 10 samples, and two from the next 10 samples. Available levels of sodium and pH were analyzed by standard techniques (United States Salinity Laboratory Staff 1954).

Soil compaction was measured with a hand-held penetrometer scaled from 0 to 4.5 ton/ft^2 (0-4.5kg/cm^2). The load required to read 4.5 ton/ft^2 (4.5kg/cm^2) was 17 lb (7.7 kg). Twelve measurements were taken in a grid pattern with 46-ft (14-m) spacing, on each site, every 3 weeks from May to October, during the second year of the study, for a total of 96 measurements per site.

Analysis of variance and Tukey's multiple comparison procedure (Kleinbaum and Kupper 1978) were used to compare plant canopy cover, average aboveground biomass, and soil properties among site types, months, and years. Regression analyses were used to compare peak standing crop and plant canopy cover of rillscale to soil characteristics.

RESULTS

Plant Canopy Cover

The plant canopy cover of rillscale ranged from 1 to 8 percent on the mine spoils, and rillscale comprised between 40 and 94 percent of the total cover on these sites (table 1). Yet, rillscale was nearly absent on the sagebrush-grasslands. The cover of rillscale did not differ significantly ($P > 0.1$) from month to month, yet it varied ($P < 0.05$) between years. In 1979, the cover of rillscale was higher ($P < 0.05$) on reclaimed spoils than other sites, and was similar ($P > 0.1$) on semireclaimed spoils, old spoils, and sagebrush-grass rangelands. However, in 1980, canopy cover of this pioneer plant increased ($P < 0.001$) on semireclaimed spoils and decreased ($P < 0.05$) on other spoils. This resulted in similar cover values on the mine spoils, but higher ($P < 0.05$) cover values on these sites than on the sagebrush-grasslands. Plant canopy cover of rillscale on bentonite mine spoils was negatively correlated with penetrometer readings ($r = -0.52$, $P = 0.001$) and sodium concentrations ($r = -0.57$, $P = 0.001$), and positively correlated with pH ($r = 0.26$, $P = 0.1$).

Plant Standing Crop

Plant standing crop of rillscale ranged from less than 3 lb/acre (3 kg/ha) to 169 lb/acre (190 kg/ha), and accounted for 40 to 93 percent of the total standing crop on the mine spoils; whereas rillscale comprised only a small portion (<1 percent) of the standing crop on sagebrush-grasslands (table 2). In 1979, standing crop of rillscale was higher ($P < 0.05$) on reclaimed spoils (averaging 138 lb/acre (155 kg/ha) than on other sites, and did not differ ($P > 0.1$) on old spoils,

Table 1.--Range and average percent plant canopy cover of rillscale and percent of total plant cover on bentonite mine spoils and sagebrush-grass rangelands near Alzada, Mont., in 1979 and 1980.

	1979			1980		
	Percent canopy cover		Percent of	Percent canopy cover		Percent of
Site type	Range	$\bar{x}$	total cover	Range	$\bar{x}$	total cover
Old spoils	<1-6	2.6^1	68	<1-4	1.8^2	72
Reclaimed spoils	8-9	8.3^2	60	3-5	3.6^2	40
Semireclaimed spoils	<1	<1^1	46	3-7	4.9^2	94
Sagebrush-grasslands	<1	<1^1	<1	<1	<1^1	<1

^{1,2}Means followed by the same letter superscript (within years) were not significantly different ($P > 0.05$).

semireclaimed spoils, and sagebrush-grasslands. However, in 1980, the standing crop of rillscale decreased ($P < 0.05$) on reclaimed and old spoils and increased ($P < 0.01$) on semireclaimed spoils. In 1980, the standing crop of rillscale was higher ($P < 0.1$) on semireclaimed spoils than on other sites, was higher ($P < 0.05$) on reclaimed spoils than on old spoils or sagebrush-grasslands, and was similar ($P > 0.1$) on old spoils and sagebrush-grass sites. Plant standing crop of rillscale on the bentonite mine spoils was negatively correlated with penetrometer readings ($r = -0.29$, $P = 0.07$) and sodium concentration ($r = -0.55$, $P = 0.001$), and positively correlated with pH ($r = 0.46$, $P = 0.003$).

Soils

Soils characteristics were highly variable on the bentonite mine spoils. In general, acidic pH values, high sodium concentrations, and compaction were common. More than 50 percent of the pH readings on old mine spoils were moderately to strongly acidic (table 3). Eight percent of the readings on reclaimed spoils were strongly acidic (pH 4.0 to 4.9), while pH values on semireclaimed spoils and sagebrush-grasslands were all slightly acidic (pH 6.0 to 6.9) to slightly alkaline (pH 7.0 to 7.9).

Sodium concentrations also were highly variable. Average concentrations on old spoils ranged from less than 2,000 ppm (10 percent of the samples) to more than 7,000 ppm (35 percent of the samples) (table 4). Average sodium concentrations on the reclaimed spoils were all less than 4,600 ppm, while 63 percent of the samples from semireclaimed spoils averaged between 4,600 and 6,900 ppm. Eighty-eight percent of the samples from sagebrush-grass rangelands contained sodium levels of less than 2,000 ppm (table 4).

Between 31 and 53 percent of the penetrometer readings on bentonite spoils averaged between 4.0 and maximum reading (4.5 ton/ft^2). Only 7 percent of the readings on the sagebrush-grasslands averaged above 4.0 (table 5). The majority of the penetrometer readings on the sagebrush-grass rangelands averaged less than 2.0, while fewer than one-third of the readings on the bentonite spoils averaged less than 2.0.

DISCUSSION

Bentonite mining activities and resultant spoil piles in southeastern Montana provided environments suitable for the establishment of rillscale. The presence and dominance of rillscale on bentonite mine spoils demonstrated the ability of this plant to rapidly colonize barren sites. The success of rillscale on the mine spoils (as plant cover and standing crop), when compared to seeded species or other native plants, was attributed to its adaptation to the climatic and edaphic conditions of the area, the absence (or near absence) of competitive vegetation, and an adequate seed source. The most inhibiting feature of the sagebrush-grasslands for the growth of rillscale was competition from other plants. The few rillscale plants observed on the sagebrush-grassland communities were limited to barren microsites.

The negative correlations of the cover and production of rillscale with penetrometer readings and sodium concentrations and positive correlation with pH indicate that certain soil (or spoil) characteristics are inhibiting to the growth of rillscale on bentonite mine spoils. With increasing compaction, excessive sodium concentration, and low pH, rillscale is less likely to grow. High compaction lessens the likelihood that plant roots will be able to

Table 2.--Range and average plant standing crop of rillscale, and percent of total standing crop on bentonite mine spoils and sagebrush-grass rangelands near Alzada, Mont., 1979 and 1980

	1979			1980		
	Plant standing crop (lb/acre)		Percent of	Plant standing crop (lb/acre)		Percent of
Site type	Range	$\bar{x}$	total crop	Range	$\bar{x}$	total crop
Old spoils	3-65	29[1]	57	0-55	19[1]	40
Reclaimed spoils	117-169	138[2]	50	54-79	68[2]	51
Semireclaimed spoils	10-21	16[1]	49	101-140	120[3]	93
Sagebrush-grasslands	0-3	2[1]	<1	0-2	1[1]	<1

[1,2,3]Means followed by the same letter superscript (within years) were not significantly different ($P > 0.05$).

Table 3.--Classification of soil samples (0-4 inches) taken on bentonite mine spoils and sagebrush-grasslands near Alzada, Mont., according to pH.

Classification	pH	Percent of samples			
		Bentonite mine spoils			Sagebrush-grasslands
		Old	Reclaimed	Semireclaimed	
Strongly acidic	(4.0 - 4.9)	45	8	0	0
Moderately acidic	(5.0 - 5.9)	15	0	0	0
Slightly acidic	(6.0 - 6.9)	25	33	63	25
Slightly alkaline	(7.0 - 7.9)	15	59	37	75

Table 4.--Distribution of soluble and exchangeable sodium concentrations in soil samples (0-4 inches) taken on bentonite mine spoils and sagebrush-grass rangelands near Alzada, Mont.

Na concentration (ppm)	Percent of samples			
	Bentonite mine spoils			Sagebrush-grasslands
	Old	Reclaimed	Semireclaimed	
0 - 2,000	10	33	0	88
2,000 - 4,600	40	67	37	12
4,700 - 6,900	10	0	63	0
> 7,000	40	0	0	0

Table 5.--Distribution of penetrometer readings taken on bentonite mine spoils and sagebrush-grass rangelands near Alzada, Mont.

Penetrometer reading (ton/ft^2)	Percent of samples			
	Bentonite mine spoils			Sagebrush-grasslands
	Old	Reclaimed	Semireclaimed	
0 to 0.9	4	5	2	39
1 to 1.9	11	20	19	28
2 to 2.9	13	17	30	18
3 to 3.9	19	20	18	8
4 to 4.5	53	38	31	7

penetrate the substrate. However, halophytic plants such as rillscale generally can become established in high-sodium media. Sodium concentrations on some of the mine spoils are apparently towards the upper range of tolerance for this plant. Further, rillscale appears to be more highly adapted to neutral or slightly alkaline soils, and is less tolerant of acidity. Low pH values are caused by the formation of sulfuric acid from inherent sulfate ions which neutralizes the alkaline effects of the spoil (Bjugstad and others 1981).

The combination of these factors may explain the lower cover (in 1979) and production (in both years) of rillscale on old spoils, compared to reclaimed spoils. High penetrometer readings, high sodium concentrations, and low pH were very common on old spoils, and comparatively less common on reclaimed spoils. Despite the near absence of competition from other plants on the old spoils, rillscale was inhibited by adverse spoil characteristics.

Differences in the plant cover and production of rillscale on semireclaimed spoils are more difficult to explain. The 1979 data were collected the first growing season after the spoils materials were recontoured and spread with topsoil. The low cover and standing crop of rillscale on semireclaimed spoils in 1979 suggest that at least one growing season is required for the accumulation of rillscale seeds to a level where this plant becomes an important component of the plant community. The flourish of rillscale the second year after reclamation may be interpreted as evidence of an adequate seed source, acceptable soil conditions, and very little competition from other plants. Acidic pH readings were not detected on the semireclaimed spoils, and these spoils were not as compacted as old spoils. Although most samples registered between 4,700 and 6,900 ppm of soluble and exchangeable sodium, none of the samples registered above 7,000 ppm. (Forty percent of the samples on old spoils were above 7,000 ppm.) Plant competition was unlikely on the semireclaimed spoils, because rillscale accounted for over 90 percent of the cover and production on these sites in 1980.

The decline in the plant canopy cover and standing crop of rillscale on reclaimed and old spoils in 1980, contrasted to the dramatic increase on semireclaimed spoils, indicated that the growing environments on old and reclaimed spoils have characteristics nearing the tolerance limits of rillscale, and that when this plant is stressed by drought, it is less likely to grow. The inhibiting feature for rillscale on reclaimed spoils, as compared to semireclaimed spoils, was likely competition from other plant species and possibly a few microsites of acidic soils. Otherwise, penetrometer readings were comparable on both reclaimed and semireclaimed spoils, and neither site type had sodium concentrations greater than 7,000 ppm. Greater soil compaction, higher sodium concentrations, and more acidic pH were inhibiting features for the growth of rillscale on old bentonite mine spoils when compared to semireclaimed spoils. These factors, coupled with drought in 1980, resulted in lower production of rillscale on the old spoils.

This study demonstrated that rillscale, a native annual forb, is highly adapted to bentonite mine spoil environments in south-eastern Montana. However, the standing crop and plant canopy cover of rillscale are limited by excessive soil compaction, high sodium concentrations, and acidic soils on some sites, particularly in combination with low precipitation. In general, reclaimed spoils provided better growing media for the establishment of rillscale than unreclaimed spoils, in the absence (or near absence) of competitive vegetation.

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WINTER HARDINESS AND JACKRABBIT PREFERENCE IN A HYBRID POPULATION OF FOURWING SALTBUSH (ATRIPLEX CANESCENS)

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ABSTRACT: Populations of a natural hybrid of fourwing saltbush (Atriplex canescens) were planted in nurseries in northwestern Nevada and at two locations in the Mojave Desert in California. The parent populations differed in height growth, winter hardiness, and browsing preference by jackrabbits. The F_1 population was winter hardy and relatively resistant to browsing damage by jackrabbits. The apparently heritable variability demonstrated in the populations suggests the possibility of plant improvement through hybridization and selection.

INTRODUCTION

Fourwing saltbush (Atriplex canescens [Pursh] Nutt.) is one of the most widely distributed species of saltbush found on western North America rangelands (Dayton 1931). As early as 1900, fourwing saltbush was considered a valuable species for seeding on depleted rangelands (Smith 1900).

Springfield (1970) and Van Epps (1975) reported that collections of fourwing saltbush from different geographic areas were highly variable in several characteristics and that these characteristics were related to seed germination and seedling establishment. In a recent study, McArthur and others (1983) evaluated a broad spectrum of fourwing saltbush accessions at two common garden sites in Utah. They enumerated considerable variability in growth rate and growth form of the shrubs. Van Epps (1975) reported difficulty in establishing in cold environments plants of fourwing saltbush collected from relatively warm environments (e.g., plants from New Mexico planted in nurseries in northern Utah). Nord and Stallings (1975) reported that there was great variation in the browsing preferences exhibited by rabbits (presumed to be blacktailed jackrabbits (Lepus californicus)) to different collections of fourwing saltbush.

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Our purpose was to evaluate the winter hardiness and preference of jackrabbits for plants of a hybrid population of fourwing saltbush.

METHODS AND MATERIALS

In 1972, we transplanted fourwing saltbush plants grown from seed collected at three locations to a garden located at Granite Peak, some 21 miles (35 km) north of Reno, Nevada. The garden, at 5,900 feet (1 800 m) elevation, is a site that originally supported a mountain big sagebrush (Artemisia tridentata Nutt. ssp. vaseyana (Rydb.) Beetle)/Thurber needlegrass (Stipa thurberiana Piper) plant community. Average annual precipitation for the past 14 years has been 13 inches (32.5 cm). The soils of the garden are Typic Haplargids.

The sources of the seeds were: (a) 20 miles (34 km) north of Mojave, Calif., on Highway 14, elevation 2,950 feet (900 m); (b) 9 miles (15 km) north of Mojave, Calif., on State Highway 58, elevation 3,900 feet (1 200 m); and (c) near Nixon, Washoe County, Nev., elevation 3,900 feet (1 200 m).

The plants were grown for 1 year in 6 inch (15 cm) pots in a greenhouse and lath house before transplanting. The plants were planted on 39 inch (1 m) centers with 36 plants in a block for each of the sources. The blocks were separated by 39 inch (1 m) alleys. Fourwing saltbush does not occur naturally in the area.

All plants were transplanted during the summer of 1972 and were a uniform 24 inches (60 cm) in height by October. The plants of the two California sources appeared to renew growth in October 1972 after the first effective fall precipitation. In early December 1972, temperature dropped to 23°F (-5°C) for three consecutive nights at the Reno, Nev., weather reporting station. We did not have temperature recording equipment at Granite Peak, but subsequent monitoring of winter temperatures on the site indicated that nighttime minimums average 9° to 14°F (5° to 8°C) colder than Reno[1]. This particularly cold December apparently affected Atriplex canescens populations in many parts of the Great Basin (McArthur 1977).

[1]Unpublished data available from the Agricultural Research Service, Reno, Nev.

The Washoe County fourwing saltbush plants dropped all their leaves after the cold nights. Leaves on plants of the two California sources shrivelled, but initially remained on the plants. In the spring of 1973, all of the Nevada fourwing saltbush plants resumed growth. All of the low-elevation saltbush plants from California were dead. Only two of the higher elevation California plants survived the winter. All of the surviving fourwing saltbush plants flowered profusely in 1973. The surviving plants from the California source were both pistillate. Seeds collected from the two pistillate plants were used in various experiments over the next 9 years (fig. 1).

The abundant seeds (F_1) produced in 1973 were cold-moist stratified at 35°F (2°C) for 4 weeks and then planted in the greenhouse. The resulting seedlings were transplanted into a large block of 150 plants on 39 inch (1 m) centers at Granite Peak. Into this garden we also transplanted plants grown from seed obtained at the Washoe County, Nev., collection site of the staminate parent plants. The seeds produced by these hybrid plants (F_2) were collected in 1975. The seedlings from the hybrid plants were transplanted to Churchill Canyon, Nev., and to Granite Peak in 1975.

Churchill Canyon is located about 11 miles (18 km) northwest of Yerington, Nev., at 4,660 feet (1 420 m) elevation. Annual precipitation is estimated at 6 inches (15 cm) (Blackburn and others 1969). Soils on the garden site are Typic Camborthids. This is a very xeric site that naturally supports a basin big sagebrush (*Artemisia tridentata* ssp. *tridentata* Nutt.)/Nevada ephedra (*Ephedra nevadensis* Wats.) plant community (Young and Evans 1973).

At the Churchill Canyon plot, we transplanted plants of both parent collections (Mojave and Washoe) obtained from remnant seed and F_1 seed obtained from the same pistillate plants at Granite Peak the previous season. In addition, we included plants of the diploid or gigas form of fourwing saltbush (Stutz and others 1975) grown from seed obtained from the Intermountain Forest and Range Experiment Station, USDA Forest Service.

We collected seed in 1975 from the F_1 plants planted at Granite Peak in 1974 and repeated the plantings at Granite Peak and Churchill Canyon. In 1976, seed collected from the F_1 plants at Granite Peak was used to establish a garden at the Gund Research and Demonstration Ranch, Grass Valley, Nev.

The Gund Ranch garden is located on an alluvial fan at 5,440 feet (1 660 m) elevation. The site supports a Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis* (Rydb.) Beetle and Young)/cheatgrass (*Bromus tectorum* L.) community (Young and Evans 1980). Annual precipitation was estimated at 8 inches (20 cm). Soils of the site belong to the Xerollic Haplargids subgroup.

Seeds collected from the F_1 plants at Granite Peak, plus seeds of the parents, were used to grow plants that were transplanted back to Granite Peak and to two locations in the Mojave Desert in 1980. The Mojave locations were 3 miles (5 km) west of Ridgecrest 3,340 feet (1 020 m) and 6 miles (10 km) north of Mojave 3,200 feet (975 m), both corresponding to the low-elevation collection site.

In all of the gardens, we annually collected data on height, persistence, and utilization by jackrabbits. Jackrabbit utilization was rated on a scale of 10 to 100 with 10 being no utilization, 20 slight utilization, 50 moderate utilization, 75 use of twigs to 0.20 inches (0.5 cm) diameter, and 100 the digging out of the plant crowns. Data were subjected to analysis of variance. Duncan's multiple range test was used to separate means where appropriate. Nonparametric statistical analysis was used to analyze the jackrabbit preference data (Siegel 1956).

RESULTS

Granite Peak - Initial Nursery

Plants of fourwing saltbush grown from seed collected from the surviving pistillate plants of the high elevation Mojave source were planted back at the Granite Peak nursery in 1974 (table 1). All of these plants survived and were still alive in 1982. Their growth was compared to the growth of plants of the staminate parent originally collected in Washoe County, Nev. The F_1 hybrid plants were considerably more vigorous, reaching a height of 39 inches (1 m) when planted at 39 inches (1 m) spacing. The F_1 plants flowered and produced some seed the first season. The nursery at Granite Peak did not suffer jackrabbit predation in 1974.

Churchill Canyon Nursery

In 1975, we planted both F_1 and F_2 seed plus plants of both parents at Churchill Canyon and Granite Peak (table 2). The natural plant communities found at the two sites indicate the Churchill Canyon location is much more xeric than Granite Peak.

There was no significant ($P \leq 0.05$) difference in initial establishment of transplants at Churchill Canyon (table 2). The nursery was protected by a jackrabbit-proof fence so there was no predation. Greatest first-season growth was made by the Washoe parents and plants from the gigas diploid source. Least growth was made by the Mojave parent and the hybrids. The height of the Mojave parent ranged from 8 to 20 inches (20 to 50 cm) and the Washoe parent from 20 to 32 inches (50 to 80 cm) at the end of one spring season (fig. 2). The F_1 population ranged in height from 12 to 24 inches (30 to 60 cm) and the F_2 from 8 to 24 inches (20 to 60 cm).

1971 Original seed collections of fourwing saltbush

Mojave Desert Low elevation	Mojave Desert High elevation	Washoe County Nevada

1972 Planted at Granite Peak, Nevada

Mojave Desert Low elevation	Mojave Desert High elevation	Washoe County Nevada
All plants winterkilled	Two pistillate plants survived	All plants survived

1973 Plants hybridized

1974 F_1 plants at Granite Peak

1975 Both F_1 and F_2 plants at Granite Peak
F_1 plants at Churchill Canyon

1976 F_2 plants at Granite Peak and Churchill Canyon

1977 F_2 plants at Gund Ranch

1979 F_2 plants at Ridgecrest, Mojave, and Granite Peak

Figure 1.--Sequence of plant material used in study.

Table 1.--Survival and height growth of F_1 hybrid and Washoe County, Nev., collections of fourwing saltbush in a garden located at Granite Peak, Nev.[1]

Plant material	Number planted 1974	1974		1975		1982	
		Survival	height	Survival	height	Survival	height
		%	cm	%	cm	%	cm
F_1 hybrid plants	150	100	50	100	100	100	100
Washoe County, Nevada collection (staminate parent of hybrid)	20	100	40	100	60	85	60

[1]There were no significant differences among means.

Table 2.--Survival and height of F_1, F_2, Washoe County (Nevada) and Mojave (California) collections and gigas diploid fourwing saltbush plants at Churchill Canyon and Granite Peak garden sites[1] at the end of the growing season.

Garden Location and Plant Material	Survival and height/over time					
	1975		1976		1982	
	Survival	Height	Survival	Height	Survival	Height
	%	cm	%	cm	%	cm
Churchill Canyon						
F_1 hybrid	90	50b	90a	80b	80a	100ab
F_2 hybrid	80	40b	60b	60b	40b	80b
Washoe parent	90	70ab	60b	80b	40b	100ab
Mojave parent	80	40b	10c	80b	10c	80b
Gigas diploid	90	100a	80ab	120a	60ab	120a
Granite Peak						
F_1 hybrid	90a	50	80a	100a	80a	100a
F_2 hybrid	80a	30	20b	60b	20b	60b
Washoe parent	10b	30	0b	0c	0b	0c
Mojave parent	80a	40	0b	0c	0b	0c
Gigas diploid	20b	60	0b	0c	0b	0c

[1]Churchill Canyon garden protected by jackrabbit-proof fence. Means within columns, within locations followed by the same letter are not significantly different at the 0.05 level of probability as determined by Duncan's multiple range test. No letters indicate no significant differences.

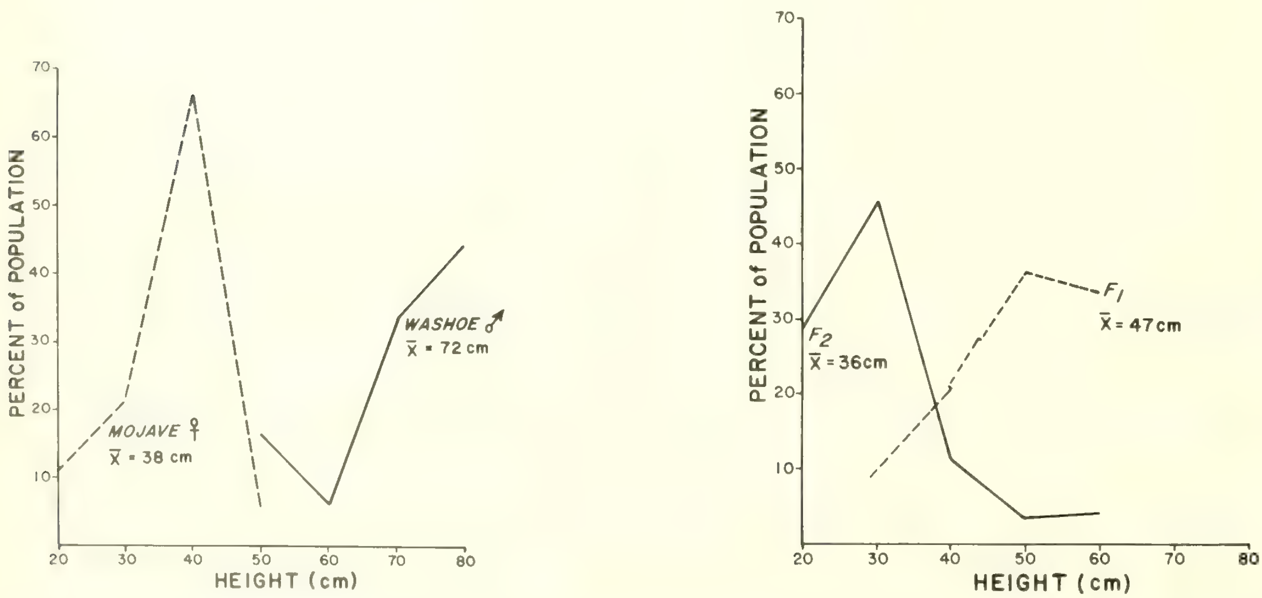

Figure 2.--Height (cm) distributions of parents (left) and F_1 and F_2 generations (right) of fourwing saltbush grown at Churchill Canyon, Nevada, in 1975 at the end of the first growing season after transplanting.

In the spring of 1976 at Churchill Canyon, only 10 percent of the fourwing saltbush plants of the Mojave source were alive; however, 80 percent of the plants of the Washoe parent were alive. (Data not shown; figures in table 2 are for the end of the growing season in 1976, a period of severe drought at the site). Fourwing saltbush plants of both the F_1 and F_2 populations survived the winter although 20 percent of F_2 plants died by the end of the growing season.

By the end of the second growing season (1976), plants from the gigas source had significantly ($P < 0.05$) more growth than plants of any other source.

In 1982, 7 years after the transplants were established at Churchill Canyon, the F_1 hybrid and gigas diploid populations had the greatest survival rates (table 2). The 39 inches (1 m) spacing used in this nursery probably greatly exceeded the site potential. A wider spacing of the plants probably could have increased survival.

Granite Peak - Second Nursery

Predation by jackrabbits at Granite Peak in 1975 severely damaged many of the fourwing saltbush plants (table 2). The increase in jackrabbit predation between 1974 and 1975 apparently was a result of: (a) an increase in the jackrabbit population, (b) a relatively dry and short growing season that limited production of forage, and (c) heavy grazing by cattle outside the nursery exclosure where the forage had been rested the previous season. Transplants of the Washoe parent and the plants of the gigas source were severely browsed the first season they were transplanted. The Mojave parents and the F_1 and F_2 hybrids were relatively resistant to jackrabbit browsing.

On the jackrabbit preference scale, the Mojave parent had an average rating of 12 and the Washoe parent 99 (fig. 3). The F_1 population was nearly as resistant as the Mojave parent. F_2 plants showed a wide range of jackrabbit browsing from 10 to 100 on the rating scale, but the bulk of the population was not preferred by jackrabbits.

The Mojave parent plants of fourwing saltbush survived the jackrabbits, but succumbed to winterkill at Granite Peak (table 2). The combination resulted in complete mortality of plants from the gigas source in the Granite Peak Nursery. In 1982, 80 percent of the F_1 plants and 20 percent of the F_2 populations were all that persisted.

Gund Ranch Nursery

Initial establishment of fourwing saltbush transplants in the Gund Ranch nursery was excellent (table 3). Again, the Washoe parent, gigas, and F_1 hybrid populations had the greatest first season growth.

During the winter of 1977-78, the fourwing plants in the nursery were subjected to severe jackrabbit browsing. This hedging, combined with winterkill, eliminated all but the hybrid populations by 1979. The plants of the hybrid populations were severely hedged by jackrabbit browsing during the next 3 years.

Mojave Nurseries

When the parent and F_2 populations were planted in nurseries in the Mojave Desert, the Mojave parent population had, numerically, greatest survival and height growth (table 4). These plants were protected from jackrabbit browsing, but the plants in the Ridgecrest nursery were browsed by other small animals.

DISCUSSION

Studies by Stutz (1978) have demonstrated that the Atriplex species are a rapidly evolving group with a great deal of genetic variability. Results from this present study indicate that, for the characteristics of winter hardiness and preference by jackrabbits, much variability that is apparently heritable can be found in fourwing saltbush populations. The potential for selection from hybrid populations for these characteristics is quite apparent.

Of immediate practical significance is the demonstrated lack of winter hardiness shown by most of the plants from the Mojave Desert. As previously shown by Van Epps (1975), knowledge of the seed source is a requirement when purchasing seed of fourwing saltbush for seeding on ranges where winter hardiness may be a problem.

Unfortunately, we did not record jackrabbit browsing of the fourwing saltbush plants by gender. There is evidence that different species of browsers show preference for either pistillate or staminate plants.[2]

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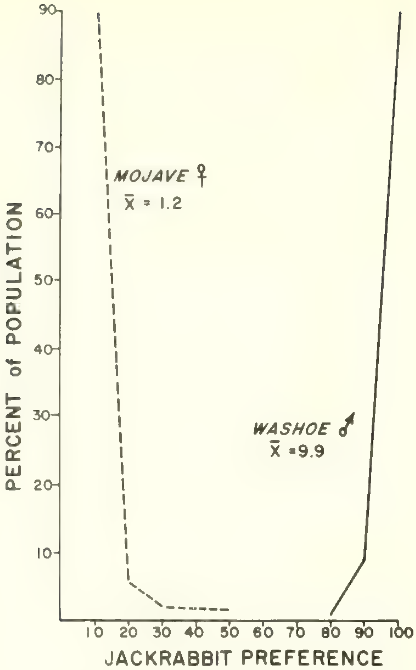
[2]Personal communication from Dr. E. Durant McArthur, USDA Forest Service, Shrub Sciences Laboratory, Provo, Utah.



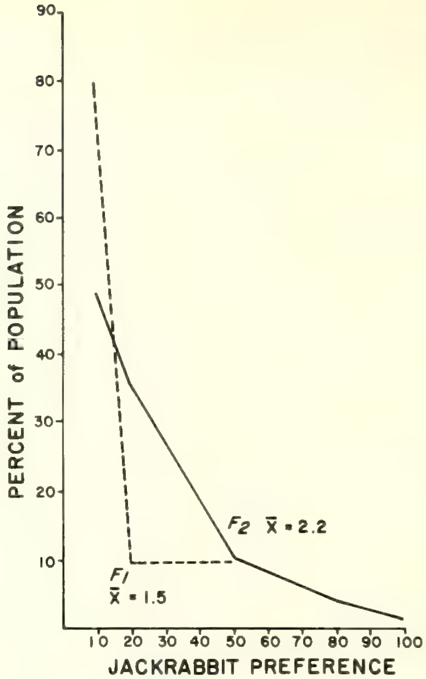


Figure 3.--Preference of jackrabbits for fourwing saltbush plants of Mojave and Washoe parents (left) and F_1 and F_2 populations (right) at Granite Peak in 1975. Rating of 10 indicates no discernible use, and 100 the digging of the plant crowns from the ground.

Table 3.--Height and survival of F_1, F_2, Washoe County (Nevada) and Mojave (California) collections and diploid fourwing saltbush plants at Gund Ranch Garden. Plants transplanted in 1977.[1]

Plant material	Height and survival over time					
	1977		1978		1982	
	Survival	Height	Survival	Height	Survival	Height
	%	cm	%	cm	%	cm
F_1 hybrid	100	60ab	80a	60	80	60
F_2 hybrid	100	50b	40b	50	20	50
Washoe parent	100	60ab	0c	0	0	0
Mojave parent	90	40b	0c	0	0	0
Gigas diploid	100	80a	10c	40	0	0

[1]Means within columns followed by the same letter are not significantly different at 0.05 level of probability as determined by Duncan's multiple range test. No letters indicate no significant differences.

Table 4.--Survival and height of Mojave and Washoe parents and F_2 populations of fourwing saltbush plants at two locations in the Mojave Desert of California. Plants transplanted in 1980[1].

Garden location and plant material	1981 Survival	Height
	%	cm
Ridgecrest		
Mojave parent	87	35
Washoe parent	67	33
F_2	60	33
Mojave		
Mojave parent	89	40
Washoe parent	86	25
F_2	67	23

[1]There were no significant differences among means.

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SURFACE SOIL AND SEEDBED ECOLOGY IN SALT-DESERT PLANT COMMUNITIES

Bruce A. Roundy, Raymond A. Evans, and James A. Young

ABSTRACT: The salt-desert seedbeds are harsh environments for seed germination and seedling growth. In the absence of frequent spring rains the total water potential of the surface soil decreases rapidly as soil matric and osmotic potentials decrease due to water loss and upward movement of salts. Even a moderately saline soil may have much lower water potentials than nonsaline soil due to the low osmotic potential of the soil solution. Soil surface cracks are important safe sites for germination and seedling emergence in these seedbeds.

INTRODUCTION

Salt-desert shrub vegetation, composed dominantly of chenopods (West 1983), has been estimated to occupy 37 to 42 million acres (15 to 17 million hectares) in the western United States (Branson and others 1967; Küchler 1964). Caldwell (1974) and West (1983) have characterized the environment of saline deserts as having high seasonal temperature and precipitation fluctuations resulting in a short period of time when active growth is not limited by extreme temperatures and lack of moisture.

Precipitation in the Great Basin mainly occurs in fall, winter, and spring. Storms producing effective precipitation become less frequent, but possibly more critical to seedling establishment, from March through June or July as temperatures become favorable for germination and growth (fig. 1). Chemical and physical properties of salt-desert soils may affect soil water availability to plants during this critical spring period or may have a direct effect on germination, emergence, and growth. An understanding of the characteristics of salt-desert soils is not only necessary to understand natural plant distribution, but is also necessary in determining range improvement and management practices. This paper will discuss some of the properties of salt-desert soils that affect plant distribution, growth, and establishment. It also presents water potential, salinity, and soil penetrability data for a salt-desert soil in central Nevada.

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LITERATURE

Much research has been devoted to the description and classification of salt-desert communities and soils in an effort to relate plant distribution to site characteristics (Kearney and others 1914; Shantz and Piemeisel 1924 and 1940; Flowers 1934; Billings 1945; Fauntin 1946; Gates and others 1956; Vest 1962; Mitchell and others 1966; Branson and others 1967; West and Ibrahim 1968; Goodman 1973; Miller and others 1982). Distribution and growth of salt-desert species have been related to numerous edaphic factors and interactions of the factors. Some important factors are: (1) tolerance of plants to total salt content of the soil (Billings 1945; Bolen 1964; Daubenmire 1970; Dodd and Coupland 1966; Flowers 1934; Hunt and Durrel 1966; Kearney and others 1914; Keith 1958; Ungar 1962 and 1966; Ungar and others 1969), (2) tolerance to relative amounts of specific ions in the soil solution (Flowers 1934; Heimann 1966; Naphan 1966; Tiku 1975), (3) depth of soil salinity (Billings 1945; Fautin 1946; Shantz and Zon 1924), (4) tolerance to flooding and poor soil aeration (Daubenmire 1970; Dodd and Coupland 1966; Evans 1953; Flowers 1934; Shantz and Piemeisel 1940), (5) water table depth and quality of ground water (Billings 1951; Bolen 1964; Daubenmire 1970; Fautin 1946; Flowers 1934; Harris and others 1924; Hunt and Durrel 1966; Jackson and others 1956; Robinson 1958; Shantz and Zon 1924; Shantz and Piemeisel 1924 and 1940; White 1932), and (6) soil texture as related to geology and erosion patterns (West and Ibrahim 1968). Other important considerations in relating growth and distribution of halophytes to soil conditions include: (1) total soil moisture potential and the proportionality of its components, osmotic and matric potential (Branson and others 1967; Goodin 1975; Miller and others 1982), (2) seasonal variability of such factors as salinity and moisture as related to germination and growth (Evans 1953; Jackson and others 1956; Goodin 1975), (3) ecotypic adaptation to specific soil conditions (Clark and West 1971; Goodin 1975; Goodman and Caldwell 1971; Goodman 1973; Workman and West 1967 and 1969), and (4) the synecological context in which the plant occurs relative to its ability to compete and reproduce (Billings 1952; West and Tueller 1971).

The internal drainage of the Great Basin has resulted in an accumulation of salts and fine sediments in the many closed basins created by basin and range faulting in the Miocene (Papke 1976). The predominant ions accumulated in surface soils of many valleys of the Great Basin are Na, Cl, and SO_4 with comparatively little Ca and Mg (Shantz and Piemeisel 1940; Gates and others 1956; Vest 1962; Stuart and others 1971; Ando 1958;

Roundy 1983[1]). These sodium salts are highly soluble and reduce the total soil water potential by reducing the soil solution osmotic potential linearly with decreasing water content (Roundy 1983)[1]. The high sodicity of these fine-textured soils also reduces infiltration (Hayward and Wadleigh 1949). Soil salts may also limit germination and growth by entering the seed or plant and creating nutritional imbalances or interfering with physiological processes (Bresler and others 1982). In addition to Na, high B concentrations have been reported in salt-desert soils (Robinson 1970) and may limit growth of some plants.

Surface soil salinity may vary with season, precipitation, and capillary rise from the water table (Jackson and others 1956). High winter precipitation may increase surface salinity by raising the water table so the capillary fringe is near the soil surface. Salts are deposited on the surface as water evaporates (Richards 1954). If the water table is deep or evapotranspiration breaks the capillary chain, surface salinization stops (Jackson and others 1956). Lowland Great Basin soils vary in amount and vertical concentration of salts due to differences in depth to the water table. Spring precipitation may increase soil osmotic potential by leaching salts accumulated in the surface soil or by removing them in runoff water and by diluting the soil solution. Teakle and Burvill (1938) found substantial leaching of salts in sandy and medium-textured soils of western Australia, but not in heavy-textured soils. In the Thar Desert, India, rainy season precipitation leached salts and increased subsurface soil moisture, resulting in increased plant and soil osmotic potentials (Rajpurohit and Sen 1980). Zallar and Mitchell (1970) suggested that autumn rains leached salts on dry hard-pan sites in Australia, allowing germination and establishment of salt-tolerant grasses. Soil salinity and sodicity decreased after contour furrowing in southeastern Montana presumably due to increased infiltration and leaching (Soiseth and others 1974). Spring rains could also decrease the osmotic potential of the subsurface soil solution by washing down salts that have precipitated out on the soil surface.

Salt-desert chenopods accumulate high amounts of Na, K, and Cl (Eckert and Kinsinger 1960; Rickard 1965; Chatterton and others 1970; Wiebe and Walter 1972). These salts may allow salt-desert shrubs to osmotically adjust to low soil water potentials (Caldwell 1974). They also increase the salinity and sodicity of the soil surface when leached from fallen litter and live plant parts (Roberts 1950; Fireman and Hayward 1952; Eckert and Kinsinger 1960; Rickard and others 1973; Sharma and Tongway 1973). Although the accumulation of salts under shrubs may reduce infiltration and result in ion concentrations toxic to some plants, the litter fall area is also associated with higher soil fertility than the interspaces (Rickard and others 1973; Charley and West 1975). Also, coarse-textured shrub mounds associated with windblown soil accumulations may be more readily leached and lower in salinity, sodicity, and B than interspace soils (Rollins and others 1968; Stuart and others 1971).

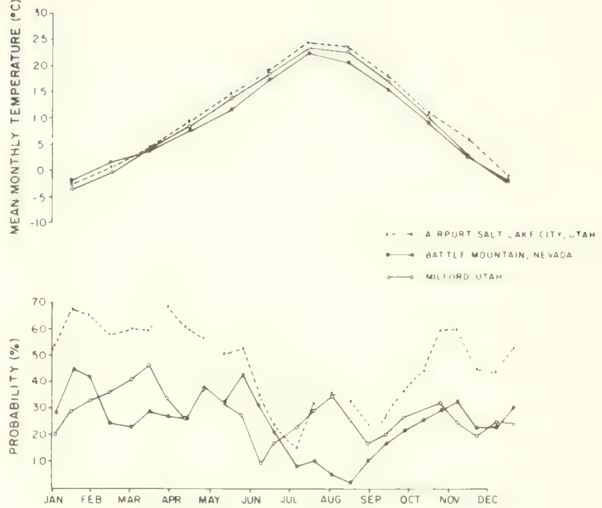

Figure 1.--Mean monthly temperatures (above, U.S. Dep. Comm. 1979, 1982) and probabilities of receiving 1 cm of precipitation in a 2-week period (below, Gifford and others 1967) for three salt-desert weather stations in the Great Basin.

The fine-textured soils generally associated with the salt-desert have high water-holding capacity, but they may limit soil water availability. Low organic matter and high sodicity result in high particle dispersion (Blackburn 1975) which causes low infiltration and hydraulic conductivity. Eckert and others (1978) have described the surface soil morphology associated with shrub mounds and interspaces of aridisols in Nevada. Regular organic matter additions from shrub litter fall result in friable, well-aggregated mound soils which have high infiltration rates. In the interspaces, the lack of organic matter and repeated wetting and drying (Miller 1971) may cause silty soils to form a platey to massive vesicular crust. This decreases soil penetrability and may restrict seedling emergence. Stephens (1980) found that slightly crusted pinnacled soil surfaces or crusted polygonal units separated by cracks were important microsites for seedling emergence in vesicular crusted soils in Nevada. Duba (1976) observed halogeton (_Halogeton glomeratus_ C. A. Mey) seedlings emerge mainly from cracks between polygonal soil surface peds. These cracks are undoubtedly safe sites (Harper 1977) for seedling emergence. They catch seeds and allow unrestricted emergence, compared to the hard crusts of the soil polygons.

[1] Roundy, Bruce A., Estimation of water potential potential components of saline Great Basin rangeland soils, unpublished draft; 1983.

Seedling establishment in deserts may occur sporadically due to one or a culmination of favorable moisture events (Noy-Meir 1973). It has been hypothesized that high seedling establishment may be the product of years of weather conditions favoring high seed set, germination, and seedling survival (Went 1955; West 1979).

METHODS

To determine the effects of high spring precipitation on salinity, water potential components, and crust penetrability, a nonsaline and a moderately saline salt-desert soil were sampled in the spring and summer of 1982 in central Nevada. The saline soil is a Gund silt-loam series identified as of the fine-silty over clayey, mixed (calcareous), mesic family of Aquic Durorthidic Torriorthents. The nonsaline soil is of the fine, montmorillonitic, mesic family of Typic Camborthids. Both soils supported a greasewood/salt rabbitbrush/basin wildrye (Sarcobatus vermiculatus (Hook.) Torr./Chrysothamnus nauseosus (Pallas) Britt. ssp. consimilis (Greene)/Elymus cinereus Scribn. and Merr.) community. The shrubs were eliminated by spraying with 3 lb/acre (3.4 kg/ha) of 2,4-D ((2,4-dichlorophenoxy) acetic acid) in the spring of 1980 and by rotobeating later in the summer. Soils were seeded to tall wheatgrass (Agropyron elongatum (Host Beauv. 'Jose') and basin wildrye (Elymus cinereus Scribn. and Merr. 'Magnar') in the fall of 1981.

Natural precipitation from November 1981 to March 1982 was average for the site at 5.5 inches (13.9 cm), but spring precipitation from April through June was 1.8 inches (4.6 cm), about 2 inches (5 cm) below average. Thus 1981-82 had a relatively wet winter and dry spring and was a good year to measure the effects of supplemental precipitation, simulated by irrigation, on soil salinity and water potential. A gradient in spring precipitation was created by irrigating the soils with a single sprinkler on four dates in May and June 1982. Water applied decreases almost linearly with the distance from the sprinkler (Hanks and others 1976). Soils were sampled at depth intervals of 0-0.4, 0.4-2.0, 2.0-4.0, 4.0-6.0, and 9.8-11.8 inches (0-1, 1-5, 5-10, 10-15, and 25-30 cm) at approximately 2-week intervals from late April through mid-August. Soils were generally sampled 2 weeks after each of the four irrigations. On each sample date, two mound and two interspace soils were sampled at distances of 8.2, 21.3, 34.5, and 52.5 feet (no irrigation) (2.5, 6.5, 10.5, and 16 m) from the sprinkler. The highest irrigation 8.2 feet (2.5 m) from the sprinkler, added a total of 4 inches (10 cm) of water to the 1.8 inches (4.6 cm) of natural rain that fell from April through June.

Total water potential of the samples was determined in psychrometer chambers. Soil osmotic potentials were estimated from measurements of volumetric wate content and electrical conductivity of the saturation extract (ECe) as described in detail by Roundy (1983)[1]. Matric potential was estimated by subtracting osmotic from total water potential. Crust penetrability was measured, in relation to precipitation and irrigation, by recording the pressure necessary to push a 0.8-inch (2-cm) diameter by 1.6-inch (4-cm) long penetrometer cone with a 30-degree angle into the soil until the top of the cone was flush with the soil surface.

RESULTS

Salinity

The saline soil had an average ECe of 7.0 $dS \cdot m^{-1}$ [2/] and an average sodium absorption ratio (SAR) of 44 in the upper 11.8 inches (30 cm). The water table in the saline soil was 6.9 feet (2.1 m) deep and fluctuated less than 1 foot (0.3 m) during the year. Except for the surface 0-0.4 inch (0.1 cm) of soil, salinity generally increased with depth (fig. 2A). Excavations indicated a zone of dry soil and therefore no capillary chain between the water table and the surface soil. Changes in salinity in the surface were a function of initial salinity conditions, precipitation, and evapotranspiration.

Salinity of the surface 0-0.4 inch (0.1 cm) was lowest in early spring following winter precipitation, then increased greatly in mid-spring as the soil began drying and salts accumulated in the surface (fig. 2A). Salinity then decreased over summer possibly as a result of wind erosion.

Subsurface salinity 0.4-6 inches (1-15 cm) increased gradually from early spring through summer probably due to an upward movement of water and salts as the upper soil dried (fig. 2A). Spring irrigation decreased this upward movement of salts, probably by continued leaching.

Important implications for plants are that the seedbed surface may be very high in salinity as the soil dries in response to warming spring temperatures, but increased spring precipitation may keep the salinity of the root zone low. The salinity of mounds and interspaces was very similar in these soils. From April through August the upper 0.4-6 inch (1-15 cm) of mounds and interspaces had an average ECe of 5.0 and 5.7 $dS \cdot m^{-1}$, respectively.

[2] $dS \cdot m^{-1}$ = decisiemen per meter = $mmho \cdot cm^{-1}$

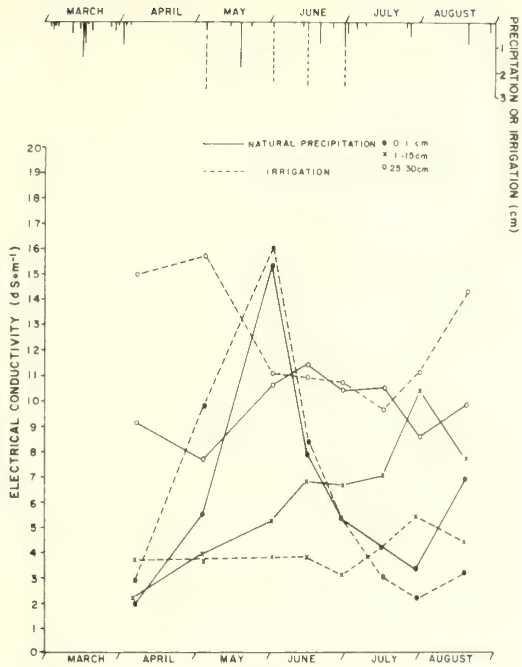

Figure 2A.--Electrical conductivity of the saturation extract for a saline soil in Grass Valley, Nevada, receiving natural precipitation and irrigation in the spring and summer of 1982.

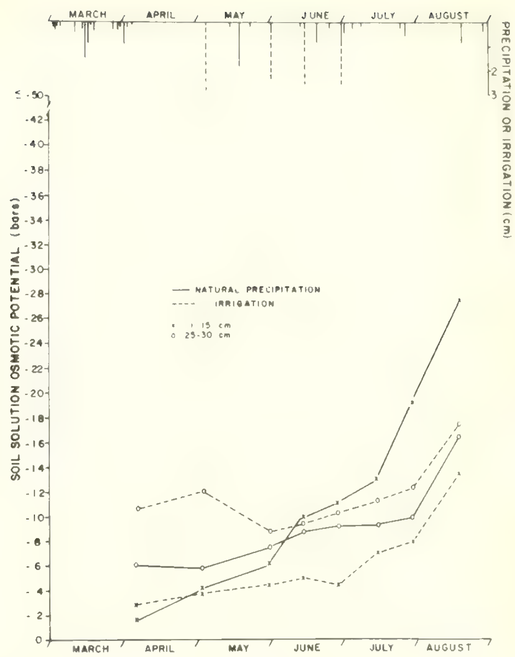

Figure 2C.--Osmotic soil water potentials for a saline soil in Grass Valley, Nevada, receiving natural precipitation and irrigation in the spring and summer of 1982.

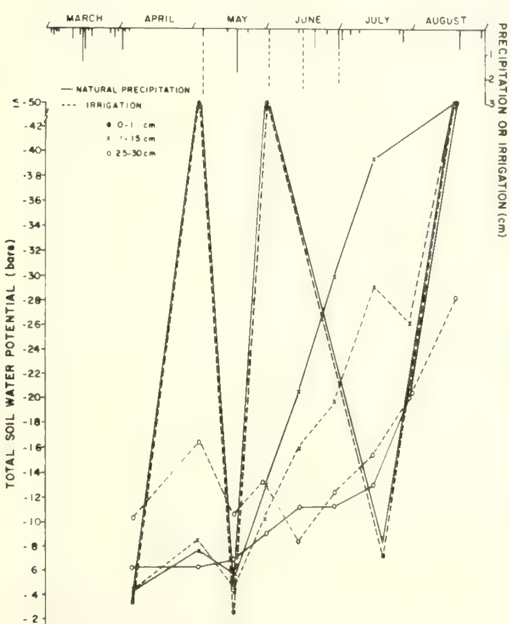

Figure 2B.--Total soil water potentials for a saline soil in Grass Valley, Nevada, receiving natural precipitation and irrigation in the spring and summer of 1982.

Figure 2D.--Matric soil water potentials for a saline soil in Grass Valley, Nevada, receiving natural precipitation and irrigation in the spring and summer of 1982.

Water Potential Components

Total water potential of the surface 0-0.4 inch (0-1 cm) of soil increased and decreased rapidly in response to precipitation and drying periods (fig. 2B). In the absence of frequent storms, seeds would either have to germinate very rapidly in the surface soil or be able to emerge from lower depths which have much higher and less fluctuating water potentials. Seeds germinating in cracks would be expected to avoid the high salinity and low water potential fluctuations of the surface soil.

Total soil water potential began decreasing in early June and continued to decrease sharply over the summer (fig. 2B). Moore and Caldwell (1972) and Everett and others (1977) have reported similar seasonal decreases in the soil water potential of shadscale (Atriplex confertifolia (Torr. and Frem.) Wats.) communities. Irrigated subsurface soil had higher total water potentials than nonirrigated soil. Irrigation decreased salinity by leaching and by increasing soil water content, thereby increasing soil osmotic and matric potentials (fig. 2). Total soil water potential of the saline soil receiving the highest irrigation (3 - 1 inch (2.5 cm) irrigations in June) still decreased rapidly from June through the summer (fig. 2B). Irrigation or storms are less effective in maintaining high soil water potentials in late spring and early summer than in early spring because of increased evapotranspiration associated with warming temperatures. Osmotic potential of the irrigated soil at 9.8-11.8 inches (25-30 cm) was more negative than that of the nonirrigated soil due to higher salinity. This difference in salinity was probably a result of horizontal variations in salinity concentrations. The irrigated soil maintained higher matric potentials at 9.8-11.8 inches (25-30 cm) than the nonirrigated soil after midsummer.

The nonsaline soil generally had higher total water potentials than the saline soil (fig. 3 and 4). The lower total water potential of the saline soil can be attributed to its osmotic potential where the matric potentials of the two soils were similar (fig. 3). The osmotic and matric potentials were each about 50 percent of the total water potential of the saline soil in the spring when soil water content was comparatively high. In April and May, soil osmotic potential decreased with depth as soil salinity increased. Matric potential increased with depth due to increasing soil water content (fig. 2C, 2D). As water content decreased in the summer, the matric potential decreased more rapidly than osmotic potential and thereby became the dominant component of the total soil water potential. As soil water content decreases to a point, matric potential decreases logarithmically. Osmotic potential in soils with highly soluble salts decreases linearly with decreasing water content. This linear decrease in soil osmotic potential, and the gradual increase in soil salinity resulted in increasingly more negative total water potentials for the saline soil compared to the nonsaline soil through the summer.

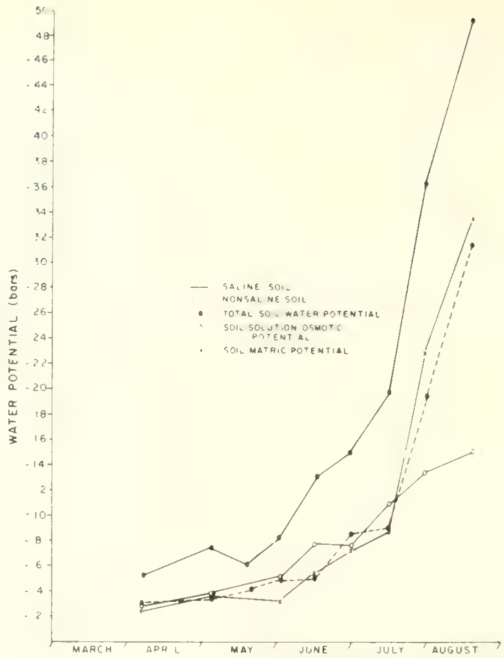

Figure 3.--Total, osmotic, and matric soil water potentials for a saline soil, and total soil water potential of a nonsaline soil for the 4-6 inches (10-15 cm) depth interval in the spring and summer of 1982 in Grass Valley, Nevada.

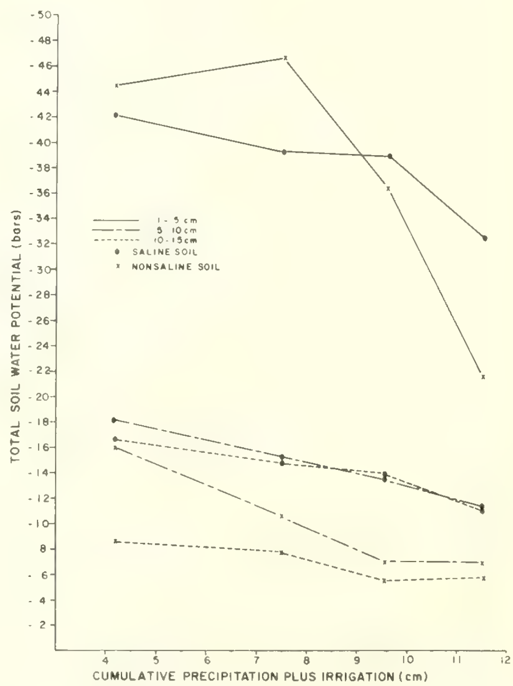

Figure 4.--Average total soil water potential of a saline and a nonsaline soil between May 18 and July 8, 1982 as a function of cumulative precipitation plus irrigation for the same time period in Grass Valley, Nevada.

Plants in these environments which can adjust osmotically may avoid the soil osmotic component of total soil water potential. These plants may grow similarly in saline and nonsaline soils, if they are tolerant to low cell osmotic potentials and accumulated ions. Differences in the ability of salt-desert plants to accumulate ions and osmotically adjust may be related to adaptability to soils of different salinities and osmotic and matric proportions of the total water potential.

The effects of increasing irrigation amounts on total soil water potential of the saline and nonsaline soils from 2 weeks after the first irrigation to 2 weeks after the last irrigation are shown in figure 4. Irrigation amount had a greater effect on increasing the total potential of the 0.4-2 inch (1-5 cm) interval of the saline soil and the 2-4 inch (5-10 cm) interval of the nonsaline soil than it had on other depth intervals. A smaller effect of irrigation amount on the water potential of deeper intervals of the saline soil may have been a result of low infiltration due to the high SAR. Since soil samples were taken 2 weeks after irrigations, the differences in water potential due to irrigation amount were probably minimized because of evapotranspirational water losses. These data underscore the importance of frequent spring rains in maintaining favorable water potentials of saline surface soils, especially for seeds that require warm temperatures for germination.

For the saline soil, mounds had total water potentials an average of 3 bars lower than interspace soils in the upper 0.4-6 inches (1-15 cm) between April and the end of June. Since salinity of the mounds and interspace soils was similar, the differences in total potential would be due to differences in matric potential rather than osmotic potential. A graph of the moisture release curves, as determined by a pressure plate, showed that at given water contents, mound soil had more negative potentials than interspace soil, even though the particle size distribution of both soils was similar.

Soil Penetrability

Shrub mound soils were much more penetrable than interspace crusts (fig. 5) and would offer little mechanical resistance to emerging seedlings. The penetrability of interspace soils increased with the amount of irrigation, but decreased again rapidly as the soil dried.

DISCUSSION

Total water potentials are at a maximum in early spring following the winter period of high precipitation and low evapotranspiration. During this time, matric potentials are high due to high soil water content. Soil solution osmotic potentials are maximum due to leaching of salts and high soil water content. With increasing temperatures and the absence of frequent spring rains, salinity may increase and water potential decrease greatly in the surface soil as it dries.

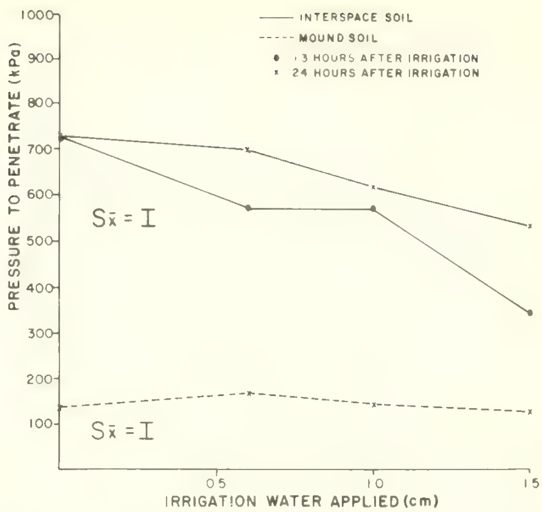

Figure 5.--Pressure required to penetrate mound and interspace salt-desert soils in Grass Valley, Nev., in relation to amount of irrigation and time after irrigation.

The vesicular crust of interspaces may soften after spring rains, but rapidly hardens as the soil dries. Cracks separating the polygons of vesicular crusts are important safe sites for seed germination and emergence. They catch the seeds which then are able to emerge unrestricted from lower soil depths where the soil water potential is much higher and fluctuates less than in the surface soil. Natural seedling emergence of halogeton, wedgescale (Atriplex truncata (Torr.) Gray) and wildrye was observed only in crevices and cracks in the salt-desert soil in this study.

High spring precipitation favors seedling establishment on saline soils by maintaining higher total soil water potentials. As the soil surface dries in late spring and early summer, salinity of the seedbed increases. Salt-bearing water from lower depths rises in response to the more negative hydraulic potential of the drier surface soil. Frequent spring precipitation slows the accumulation of salts in the surface 0.4-6 inches (1-15 cm) of soil by continued leaching and results in higher soil solution osmotic potentials. In the absence of frequent rains, seedbed osmotic and matric potentials decrease rapidly in the spring and early summer. During years of minimal spring precipitation, seedling establishment on salt-desert soils may be dependent on rapid and early root growth and the ability to osmotically adjust to maintain root growth in the wetter, but increasingly saline, subsurface soil.

Although mound soils may be higher in fertility, aggregate stability, and penetrability, they may have the same salinity and osmotic potentials, but lower matric potentials, for a given water content than interspace soils. The results of this study underscore the importance of cracks between the soil polygons as safe sites. High spring precipitation is critical to seedling establishment in salt-desert soils.

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VESICULAR-ARBUSCULAR MYCORRHIZAE ASSOCIATIONS IN ATRIPLEX CANESCENS (PURSH) NUTT. AND CERATOIDES LANATA (PURSH) J.T. HOWELL

D. L. Lindsey, S. E. Williams, W. D. Beavis and Earl F. Aldon

ABSTRACT: Generally, Atriplex canescens (Pursh) Nutt. was found to form vesicular-arbuscular mycorrhizal associations under field conditions. Several pathogenic fungi, Polymyxa graminis and Olpidium spp., commonly mistaken for mycorrhizal fungi, also were found to be associated with A. canescens roots. Spore numbers of vesicular-arbuscular mycorrhizal fungi in soil surrounding roots of A. canescens growing in natural and disturbed areas ranged from 230 to 2,090 per 100 g soil. In a greenhouse study, no or sparse infection of A. canescens and Ceratoides lanata (Pursh) J.T. Howell by five different vesicular-arbuscular mycorrhizal fungi was found. Also, no effect on growth of A. canescens or C. lanata infected with vesicular-arbuscular mycorrhizal fungi was observed.

INTRODUCTION

Vesicular-arbuscular mycorrhiza (VAM) is one of the most widespread symbioses between microorganisms and higher plants. This association of fungi and plant has been demonstrated to have significant impacts on the plant. VA mycorrhizal plants have been repeatedly shown to have increased biomass over nonmycorrhizal plants (Gerdemann 1968; Mosse 1973). Many scientists have attributed this growth response to increased uptake of phosphorus by infected plants when compared to controls (Bowen and others 1975; Tinker 1975; Rhodes and Gerdemann 1978). Enhanced uptake of other nutrients (e.g., zinc) can occur as well (Rhodes and Gerdemann 1978; Mosse 1981). Infection can influence favorable plant water relations by reducing plant resistance to water transport (Safir and others 1972; Hardie and Leyton 1981; Allen 1982), and may thus improve plant drought tolerance (Allen and others 1981). Infection can also effect changes in phytohormone levels (Allen and others 1980) and photosynthetic rates (Allen and others 1981).

The Chenopodiaceae is one of the few plant families that contains both mycorrhizal and nonmycorrhizal species. There is some controversy concerning the mycorrhizal status of chenopod species (Hirrell and others 1978; Malloch and others 1980). However, current evidence suggests that fourwing saltbush (Atriplex canescens [Pursh] Nutt.) and winterfat (Ceratoides lanata [L.] C. A., Mey) do form VA mycorrhizal associations (Miller 1979; Reeves and others 1979; Williams and Aldon 1976). An exception to these findings is a report of the absence of mycorrhizal infection of A. canescens growing near Las Cruces, N. Mex., by Staffeldt and Vogt (1974).

Only limited work has been conducted on the influence of VA mycorrhizae on survival and growth of A. canescens and there is no reported work on C. lanata. Under greenhouse conditions, Williams and others (1974) demonstrated an increase in growth of A. canescens infected with Glomus mosseae (Nic. and Gerd.) Gerd. and Trappe while Lindsey and others (1977) found no effect on survival or growth of A. canescens inoculated with G. fasciculatum (Thaxter sensu Gerd.) Gerd. and Trappe. In the only published report of the influence of VA mycorrhizae on A. canescens in field conditions, Aldon (1975) observed increased survival and growth of plants infected with G. mosseae over noninfected plants grown on a coal spoil site in northwestern New Mexico.

The objectives of this study were to: (1) evaluate the mycorrhizal status of A. canescens and VAM fungal spore populations in soil surrounding A. canescens roots on plants growing in natural and disturbed areas and (2) determine the response of A. canescens and C. lanata to five different VAM fungi under controlled conditions.

MATERIALS AND METHODS

The study area for evaluating the mycorrhizal status of A. canescens was located at the McKinley Mine in northwestern New Mexico approximately 3 miles (4.8 km) east of Windowrock, Ariz. Soil and root samples were collected beneath and from four different plants growing on a disturbed site (water harvesting study area on reclaimed coal spoil) and four plants on a

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nondisturbed alluvial site. Two collections of soil and roots were made during the spring, summer, fall, and winter to determine seasonal variations of VAM fungal spore density and percentage of the root system infected with VAM fungi. Approximately 12.9 ounces (400 g) soil was collected from the top 8 inches (20 cm) of soil beneath each plant using a 0.8-inch (2-cm) soil probe. After thoroughly mixing, spores were extracted from a 3.2-ounce (100-g) portion of each soil sample by the wet-sieving and decanting method of Gerdemann and Nicholson (1963). Spore number was determined microscopically using nematode counting dishes.

Approximately 8 inches (20 cm) of fine roots (diameter 0.8-inch (2-mm)) were collected from each plant and placed in FAA solution for transport and storage. In order to determine percentage of the roots system infected with VAM fungi, roots were cleared and stained using the technique of Phillips and Hayman (1970). The percentage of root infection was estimated by the Giovannetti and Mosse (1980) gridline intersect method. A total of 50 gridline intersects were observed per sample.

A study was conducted in the greenhouse to determine the infectivity and host specificity of five VAM fungi on A. canescens and C. lanata. Seeds of A. canescens and C. lanata were germinated on moist filter paper in petri dishes and transplanted into 6-inch (15-cm) plastic pots containing a low phosphorus soil. Each pot underwent one of six treatments. Treatments consisted of a soil with no VAM fungal spores added, or 100 spores of one of the following VAM fungal species: Gigaspora margarita Becker and Hall; Glomus fasciculatum, G. macrocarpum Tul. and Tul.; G. microcarpum Tul. and Tul.; or G. mosseae. There were four replications per treatment. After a 6-month growth period, plants were harvested and the following parameters were measured: plant height, shoot dry weight, and percentage of root systems infected with VAM fungi.

RESULTS AND DISCUSSION

Atriplex canescens from disturbed and nondisturbed plant communities throughout New Mexico were found to form mycorrhizal associations. At the McKinley Mine study area, VAM fungal infection of the roots of A. canescens plants growing on a disturbed reclaimed coal spoil site and nondisturbed sites ranged from 0 to 65 percent and 8 to 40 percent, respectively, over an 11-month period in 1980-81 (table 1). In another study, of the 47 plants collected from nondisturbed plant communities in central and southern New Mexico, 68 percent were VA mycorrhizal (table 2). These findings are in general agreement with those of Miller (1979) and Williams and Aldon (1976), except Miller (1979) found no VAM association with A. canescens plants growing on disturbed sites.

The mycorrhizal roots of plants collected from disturbed and nondisturbed plant communities contained the typical VAM fungal hyphae and vesicles, but no arbuscules were observed. However, the presence of arbuscules in VA mycorrhizae of A. canescens has been reported by Miller (1979) and Williams and Aldon (1976). The absence of arbuscules may be a signal that the degree of association between A. canescens and VAM fungi is somewhat different than that normally observed. Hirrell and others (1978) suggest that this results in a nonfunctional mycorrhizae; however, it is uncertain what constitutes a nonfunctional association. Ojala and others (1983) have demonstrated that functionality of a VAM association is very much influenced by soil extractable phosphorus, where a functional association is defined as increasing the dry weight of mycorrhizal plants as compared to controls.

In addition to VAM fungal infection, the roots of A. canescens plants collected from central and southern New Mexico were found to be infected with either of two pathogenic fungi, Polymyxa graminis Ledingham and Olpidium spp. (Braun) Rabenh (table 2). These fungi are common root inhabitants and are sometimes mistaken for VAM fungi. The effect of these fungi on A. canescens or on VAM fungi was not determined.

Spore density of VAM fungi in soil beneath plants growing on the disturbed and nondisturbed sites at the McKinley Mine was estimated for the spring, summer, fall, and winter seasons. Spore numbers of VAM fungi were generally higher in the nondisturbed soils than the disturbed soils (table 3). Spore numbers on the disturbed site ranged from a low of 230 per 100 g soil in the spring to a high of 1,300 per 100 g soil in the fall. On the nondisturbed site, spore numbers ranged from a low of 690 per 100 g soil in the fall to a high of 2,090 per 100 g soil in the spring. The spore densities found in these two habitats are considerably higher than the 1 to 10 VAM fungal spores per 100 g soil in native shrub fields in Oregon and 1 to 5 per 100 g soil in shrub areas of the Sonoran Desert of Baja Calif. reported by Rose (1980 and 1981) and the 0 to 89 per 100 g soil in desert soils in Pakistan reported by Khan (1974).

In the greenhouse study to investigate the host specificity and effectivity of five VAM fungi on A. canescens and C. lanata in a low phosphorus soil, little or no infection of the roots occurred during a 6-month growth period. A. canescens roots were infected at a very low level by only G. fasciculatum and G. margarita; neither fungus was found to stimulate growth (table 4). Only G. microcarpum infected the roots of C. lanata; however, no effect on growth was detected (table 5). The sparse infection along with the absence of arbuscules in the roots and lack of growth response in these two chenopod species infected with VAM fungi,

Table 1.--Mean percentage of mycorrhizal infection of Atriplex canescens at the McKinley Mine in northwestern New Mexico.

Plant community	1980						1981	
	April	May	July	August	September	October	January	February
Disturbed site (Reclaimed coal spoil)	39.8	0	49.0	42.3	28.5	44.5	36.0	60.5
Nondisturbed site (Alluvial)	27.0	8.0	40.3	20.8	18.8	27.0	36.0	26.5

Root samples were collected from four different plants on each site at each sampling period.

Table 2.--Percentage of Atriplex canescens plants infected with pathogenic fungi; Polymyxa graminis and Olpidium spp. in nondisturbed and disturbed sites in central and southern New Mexico.

Site status	Number of plants examined	Percentage of plants infected with		
		Olpidium spp.	Polymyxa	Both fungi
Disturbed	20	50	15	10
Undisturbed	8	75	12	0
Undisturbed	9	6	3	--

Plants grown in a nursery environment in an alluvial field soil from Rio Grande flood plain south of Albuquerque, N. Mex. 2N KCl soluble soil analysis was: NH^+, 4.9 g/g; NO_3^-, 57 g/g; Na, 20.5 g/g; Ca, 20.5 g/g; Mg, 11.0 g/g; Mn, 3.3 g/g; P, 5.0 g/g; Zn, 2 g/g; water soluble K was 20.5 g/g and total N was 0.065 percent.

Sandy, alluvial soil on native site 32.2 miles (20 km) south of Las Cruces, N. Mex.

Site near old CCC camp 48.3 miles (30 km) northwest of Albuquerque, N. Mex. (See Williams and Aldon 1976 for description of site.)

Table 3.--Mean spore count of mycorrhizal fungi per 100 gram of soil in the rhizosphere soil of Atriplex canescens at McKinley Mine in northwestern N. Mexico.

Plant community	1980			1981
	Spring	Summer	Fall	Winter
Disturbed site (Reclaimed coal spoil)	230	330	1,300	320
Nondisturbed site (Alluvial)	2,090	1,310	690	1,030

Soil samples were collected from beneath four different plants at two different times during the spring, summer, fall, and winter months.

Table 4.--Response of fourwing saltbush, Atriplex canescens, to five vesicular-arbuscular mycorrhizal fungi.

Inoculum applied to plants	Dry weight of shrubs	Height of plants	Percent of roots infected
	Grams	cm	
None - (control)	0.56	5.7	0
Glomus fasciculatum	.50	3.7	1
Glomus macrocarpum	.64	5.2	0
Glomus microcarpum	.66	5.1	0
Glomus mosseae	.62	5.8	0
Gigaspora margarita	.72	7.1	1

No significant differences between treatments.

Table 5.--Response of winterfat, Ceratoides lanata, to five vesicular-arbuscular mycorrhizal fungi.

Inoculum applied to plants	Dry weight of shrubs	Height of plants	Percent of roots infected
	Grams	cm	
None - (control)	0.27	7.2	0
Glomus fasciculatum	.30	7.1	0
Glomus macrocarpum	.31	10.4	0
Glomus microcarpum	.39	6.4	1.3
Glomus mosseae	.34	8.3	0
Gigaspora margarita	.31	6.8	0

No significant differences between treatments.

indicates that a low effectivity mycorrhizal association may have been formed.

Evidence presented in this paper and others (Miller 1979; Williams and Aldon 1976; Reeves and others 1979) suggests that A. canescens and C. lanata grown in natural plant communities are generally VA mycorrhizal. However, under controlled conditions where plants are grown in soil infested with individual species of VAM fungi, mycorrhizal functionality is not apparent. Although we have no explanation for these findings, several factors may be involved: (1) edaphic factors, such as phosphorus levels, may have a pronounced influence on the mycorrhizal dependency of A. canescens (Ojala, and others 1983); (2) plants may require a degree of physiological maturation, not possible in our greenhouse studies, before infection will occur; or (3) plants in natural habitats form mycorrhizae when growing in close proximity to mycorrhizal plants (Hirrell and others 1978).

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POTENTIAL FOR HERBICIDAL BRUSH CONTROL IN SALT-DESERT PLANT COMMUNITIES

Greg J. Cluff, Bruce A. Roundy, Raymond A. Evans, and James A. Young

ABSTRACT: Greasewood (Sarcobatus vermiculatus (Hook.) Torr) and salt rabbitbrush (Chrysothamnus nauseosus ssp. consimilis (Greene) Hall & Clem.) are two undesirable species occupying potentially productive sites in the Great Basin. Their control, with various herbicides and mixtures of herbicides at various rates and dates, was investigated. Application of 2,4-D ((2,4-dichlorophenoxy) acetic acid) at 2 lb/acre (2.2 kg/ha) acid equivalent in June resulted in 72 and 87 percent mortality for greasewood and salt rabbitbrush, respectively. Application of picloram (4-amino-3,5,6-trichloropicolinic acid) at .5 lb/acre (.6 kg/ha) plus 2,4-D at 2 lb/acre (2.2 kg/ha) was more effective for greasewood control than 2,4-D alone in one year at very early and late dates on a xeric site. Application of 2,4-D in two successive years in June resulted in excellent control of both greasewood and salt rabbitbrush and may be necessary for effective control on xeric sites.

INTRODUCTION

Greasewood (Sarcobatus vermiculatus (Hook.) Torr) and salt rabbitbrush (Chrysothamnus nauseosus ssp. consimilis (Greene) Hall & Clem.) are dominant brush species of many saline-alkaline valley bottoms and flood plains in the Great Basin. Under pristine conditions, large areas now covered with greasewood and salt rabbitbrush supported stands of perennial native grasses such as Great Basin wildrye (Elymus cinereus Scribn. & Merr.). Because of continual overgrazing and mowing of these stands, beginning before the turn of the century, only small remnant areas of native grasses remain (Lesperance and others 1978). These areas can produce considerable forage for livestock if the brush is removed and the endemic perennial grasses are released from competition. Rehabilitated stands of native grasses can be preserved through proper grazing management (Lesperance and others 1978).

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Greasewood is a much-branched, spinescent chenopod with linear, fleshy leaves. It is usually monoecious with the staminate flowers borne spirally on terminal spikes and pistillate flowers borne in the axils of leaflike bracts (Munz 1973). Greasewood is considered a useful browse plant in some areas, but losses of livestock from oxalate poisoning occur when the shrub is eaten exclusively or in large quantities (Kingsbury 1964).

Salt rabbitbrush is one of the most common subspecies of rubber rabbitbrush (Roundy and others 1980). It is a round to pyramidal-shaped shrub in the Astereael tribe of the family Compositae, with linear leaves less than 0.04 inch (1 mm) wide and perfect flowers borne in terminal rounded cymose clusters (Munz 1973). This shrub is one of the least browsed subspecies of rabbitbrush (Hanks and others 1975).

Both greasewood and salt rabbitbrush are resprouting species, so control with fire, chaining, or brush beating is generally unsuccessful. Control of C. nauseosus with fire is very erratic, even on the same site burned at the same date in different years (Robertson and Cords 1957). Efficacy of control with fire probably depends upon whether the fire is hot enough to kill the crowns. Many greasewood and salt rabbitbrush sites are very sparse and would burn only under very hazardous fire conditions.

Greasewood and salt rabbitbrush are considered difficult to control with herbicides (Parker 1978; Roundy and others 1980). C. nauseosus is effectively controlled when new twig growth exceeds 3 to 4 inches (8 to 10 cm) (Hyder and others 1958; Mohan 1973). In drought years, C. nauseosus may not produce enough new growth to be susceptible to foliar herbicides (Hyder and others 1957). Good control of greasewood may be achieved by application of 2 lb/acre (2.2 kg/ha) 2,4-D ester or amine during active growth in the spring (Parker 1978). Simultaneous control of greasewood and salt rabbitbrush with foliar herbicides depends upon proper timing of application. Herbicides should be applied to correspond with the overlap in accelerated growth phases of the two species. The accelerated growth phases of greasewood and salt rabbitbrush overlap from the last week of May to mid-June or early July depending upon the year (Roundy and others 1980).

The purpose of this study was to determine the herbicide, rate of application, and date of application producing the most effective control of greasewood and salt rabbitbrush.

MATERIALS AND METHODS

Herbicide treatments were evaluated over a 4-year period at Surprise Valley in northeastern California and at the Gund Ranch Research and Demonstration Center in central Nevada. Greasewood and salt rabbitbrush mortality was measured at least 1 year after herbicide application in seven trials at the Gund Ranch and one trial at Surprise Valley. The soils of the Gund Ranch sites were all fine-silty, over-clayey, mixed (calcareous) mesic Aquic Durorthidic Torriorthents (U.S. Department of Agriculture, Soil Conservation Service 1978), whereas the Surprise Valley soil was a fine montmorillonitic, frigid Aquic Haplic Nadurargid.

Foliar active herbicides were applied at different times from March through August each year from 1977 to 1980. Soil active herbicides were applied in the fall and winter months each year from 1978 to 1980. In plots larger than 2.5 acres (1 ha), foliar herbicides were applied in water at 10 gal per acre (95 liters/ha) with a rangeland ground sprayer which was designed for low-volume herbicide applications (Young and others 1979). Small plot areas, less than 1.2 acre (0.5 ha), were treated at 8 gal/acre (76 liter/ha), by using a backpack sprayer with low-volume nozzles with water as the carrier. Granular herbicides were applied by hand or with a rotary spreader.

Foliar herbicide and other brush control treatments were: (a) 2,4-D low volatile ester, (b) 2,4-D plus picloram, (c) dicamba (3,6-dichloro-o-anisic acid), (d) 2,4-D amine (dimethylamine salt of 2,4-D), (e) triclopyr ([(3,5,6-trichloro-2-pyridinyl)oxy]acetic acid) ester, (f) silvex (2-(2,4,5-trichlorophenoxy)propionic acid), (g) 2,4,5-T (2,4,5-trichlorophenoxy)acetic acid), (h) 2,4-D ester plus 2,4,5-T, (i) 2,4-D plus dicamba, (j) 2,4-D plus dicamba plus picloram, (k) 2,4-D dormant oil (2,4-D with diesel oil carrier applied in winter), (l) rotobeating followed by 2,4-D the next season, (m) rotobeating only, and (n) spray with 2,4-D and respray the next season with 2,4-D. Granular herbicides were: (a) picloram (10 percent pellets), (b) dicamba (5 percent granules), (c) buthidazole [3(5-(1,1-dimethylethyl)-1, 3,4-thiadiazol-2-yl)-4-hydroxy-1-methyl-2-imidazolidinone] (5 percent granules), (d) tebuthiuron (N-[5-(1,1-dimethylethyl)-1,3,4-thiadiazol-2-yl]-N,N'-dimethylurea) (20 percent granules), and (e) karbutilate (tertbutylcarbamic acid ester with 3-(m-hydroxyphenyl)-1,1-dimethylurea) (table 1).

Herbicides were applied at different rates and dates in each trial. A trial consisted of a single set of replicated treatments applied during one season on a particular site. The Gund Ranch trials differed only with respect to soil moisture conditions at the time of herbicide application. A trial was designated as relatively xeric or mesic based upon topography, growth phenology, and/or measured soil water potentials.

Greasewood and salt rabbitbrush phenology and soil water potential data were taken in trials 1, 2, 3, 5, 7, and 8 (table 1). Phenology data consisted of measurements of length and rate of elongation of new shoots. Soil water potentials were determined with thermocouple psychrometers buried 6, 18, and 36 inches (15, 45, and 90 cm) below the soil surface. Data were recorded for each date of spray.

Greasewood and salt rabbitbrush mortality was measured in each trial at least one year after treatment. Percent brush mortality in the small plots was determined by counting the total number of live and dead shrubs. In large plots, the numbers of live and dead shrubs were counted in belt transects 3 feet by 100 feet (1 m by 30 m). There were at least four small plots or belt transects for each treatment.

RESULTS AND DISCUSSION

The most consistently effective herbicide treatments for the simultaneous control of greasewood and salt rabbitbrush were: (a) 2 lb/acre (2.2 kg/ha) 2,4-D plus 0.5 lb/acre (0.6 kg/ha) picloram applied sometime from late May to July and (b) 2 lb/acre (2.2 kg/ha) 2,4-D applied sometime from late May to July (table 2). Other treatments resulted in similar control, but were not as consistent from trial to trial.

The most consistently effective herbicide treatments for greasewood control were: (a) 2 lb/acre (2.2 kg/ha) 2,4-D plus 0.5 lb/acre (0.6 kg/ha) picloram applied in June, and (b) 1 lb/acre (1.1 kg/ha) 2,4-D applied in June (table 2). Greasewood control was more effective at the low rates 1 or 2 lb/acre (1.1 or 2.2 kg/ha) of 2,4-D than the higher rate 3 lb/acre (3.4 kg/ha) (table 2). Greasewood leaves turned brown and dried within a day of 2,4-D application at 3 lb/acre (3.4 kg/ha). Greasewood appears to be hypersensitive to high rates of 2,4-D; leaves die before sufficient herbicide translocation can take place to kill the roots and stems.

The most consistently effective herbicide treatments for salt rabbitbrush control were: (a) 2 lb/acre (2.2 kg/ha) 2,4-D plus 0.5 lb/acre (0.6 kg/ha) picloram applied sometime from late May through early July, and (b) 2 lb/acre (2.2 kg/ha) 2,4-D applied in June (table 2).

Table 1.--Brush control treatments with rates and dates of herbicide application.

Trial[1]	Soil water regimes	Treatments	Rate(s)	Date(s) of application
			----Kg/ha----	-------Month/day/year---------
1	mesic	2,4-D	1.1, 2.2, 3.4	5/12, 6/1, 6/23, 7/11, 7/27/78
		2,4-D + picloram	2.2 + 0.6	5/12, 6/1, 6/23, 7/11, 7/27/78
		Silvex	3.4	6/23/78
		Triclopyr	3.4	6/23/78
		2,4-D + 2,4,5-T	3.4 (1:1 w/w)	6/23/78
		2,4-D Dormant oil	3.4	3/28/78
		Dicamba	2.2	6/23/78
		Tetuthiuron granules	0.6, 1.1	3/28/78
		Karbutilate granules	1.1, 2.2	3/28/78
		Buthidazole granules	1.1, 2.2	3/28/78
2	mesic	2,4-D	1.1, 2.2, 3.4	5/4, 5/17, 6/14, 6/28/79
		2,4-D + picloram	2.2 + 0.6	5/4, 5/17, 6/14, 6/28/79
		Silvex	3.4	6/14/79
		Triclopyr	3.4	6/14/79
		2,4-D + 2,4,5-T	3.4 (1:1 w/w)	6/14/79
		2,4-D Amine	3.4	6/14/79
		2,4,5-T	3.4	6/14/79
		Dicamba	2.2	6/14/79
		Tebuthiuron granules	0.6, 1.1	3/22/79
		Picloram pellets	0.6, 1.1, 2.2	3/22/79
		Karbutilate granules	1.1, 2.2	3/22/79
3	xeric	2,4-D	1.1, 2.2, 3.4	5/4, 5/17, 6/7, 6/14, 6/28, 7/12/79
		2,4-D + picloram	2.2 + 0.6	5/4, 5/17, 6/7, 6/14, 6/28, 7/12/79
		Silvex	3.4	6/14/79
		Triclopyr	3.4	6/14/79
		2,4-D + 2,4,5-T	3.4 (1:1 w/w)	6/14/79
		2,4-D Amine	3.4	6/14/79
		2,4,5-T	3.4	6/14/79
		Dicamba	2.2	6/14/79
4	———	2,4-D	1.1, 2.2, 3.4	6/21, 5/28/78
		2,4-D Amine	3.4	6/21/78
		2,4-D + picloram	2.2 + 0.5	6/21/78
		Dicamba	1.6, 2.2	6/21/78
5	xeric/ mesic	2,4-D	3.4	6/21-27/77
		2,4-D	1.1, 2.2, 3.4	6/13, 6/20, 6/29/78
6	———	Rotobeat 2/77 + 2,4-D	1.1, 2.2, 3.4	6/07/78
		Rotobeat 2/77 + 2,4-D	1.1, 2.2, 3.4	6/16/77, 6/07/78
		Rotobeat only	--	2/15/77
		2,4-D	1.1, 2.2, 3.4	6/07/78
		2,4-D	1.1, 2.2, 3.4	6/16/77, 6/07/78
7	mesic	2,4-D	1.4	5/22, 6/1, 6/30, 7/11, 8/01/80
		2,4-D + dicamba	1.1 (1:1 w/w)	5/22, 6/1, 6/30, 7/11, 8/01/80
		Dicamba	1.1	5/22, 6/1, 6/30, 7/11, 8/01/80
		Dicamba + 2,4-D + picloram	1.1 (4:4:1 w/w/w)	5/22, 6/1, 6/30, 7/11, 8/01/80
		Triclopyr	1.1	5/22, 6/1, 6/30, 7/11, 8/01/80
		Picloram	0.6, 1.1, 2.2	1/15/80
		Dicamba granular	0.6, 1.1, 2.2	1/15/80
8	mesic	2,4-D	2.2	6/14/79
		2,4-D + picloram	2.2 + 0.4	6/14/79
		2,4-D + dicamba	2.2 + 1.1	6/14/79

[1]Trials 1 - 7 were at the Gund Ranch, central Nevada. Trial 8 was at Surprise Valley, northeastern Californ

Table 2.--Most effective treatments for the control of greasewood and salt rabbitbrush in herbicide trials conducted in central Nevada and northeast California[1].

	Greasewood				Salt rabbitbrush			
Trial	Treatment	Rate	Date	Brush mortality	Treatment	Rate	Date	Brush mortality
		Kg/ha	Mo/day/year	%		Kg/ha	Mo/day/year	%
1	2,4-D	1.1	6/01/78	96 ab	2,4-D + pic.	2.2 + 0.6	7/11/78	100
	2,4-D + pic.	2.2 + 0.6	6/01/78	88 ab	2,4-D	2.2	6/01/78	100
	Triclopyr	3.4	6/23/78	86 ab	2,4-D	3.4	6/01/78	100
2	2,4-D + pic.	2.2 + 0.6	6/14/79	94 ab	Triclopyr	3.4	6/19/79	100
	2,4-D	1.1	6/14/79	88 ab	2,4-D + pic.	2.2 + 0.6	6/28/79	92
	2,4-D + pic.	2.2 + 0.6	6/28/79	78 ac	2,4-D	2.2	6/14/79	88
	Dicamba	3.4	6/14/79	78 ac	Dicamba	3.4	6/14/79	88
3	Dicamba	2.2	6/14/79	58 cd	2,4-D + pic.	2.2 + 0.6	5/17/79	90
	2,4,5-T	3.4	6/14/79	52 d	2,4-D + pic.	2.2 + 0.6	7/12/79	86
	2,4-D + pic.	2.2 + 0.6	7/12/79	50 d	2,4-D	2.2	7/12/79	81
4	2,4-D	1.1	6/21/78	98 a	2,4-D	3.4	5/21/78	96
	2,4-D amine	3.4	6/21/78	98 a	2,4-D	2.2	6/21/78	87
	2,4-D + pic.	2.2 + 0.6	6/21/78	93 ab	2,4-D	1.1	6/21/78	84
5[2]	2,4-D	3.4	6/29/78	100 a	2,4-D	3.4	6/13/78	100
	2,4-D	1.1	6/20/78	94 ab	2,4-D	3.4	6/29/78	99
	2,4-D	2.2	6/13/78	94 ab	2,4-D	2.2	6/13/78	98
6[3]	RB + 2,4-D	1.1	6/07/78	100 a	RB + IS + 2,4-D	2.2	6/07/78	99
	IS + 2,4-D	1.1	6/07/78	100 a	IS + 2,4-D	3.4	6/07/78	98
	2,4-D	1.1	6/07/78	100 a	2,4-D	2.2	6/07/78	93
7	2,4-D + dic.	0.6 + 0.6	6/30/80	85 a	2,4-D+pic.+dic.	1.1 (4:4:1 w/w/w)	6/01/80	100
	2,4-D	1.4	7/11/80	81 ab	Dic. granules	2.2	3/80	91
8	2,4-D + pic.	2.2 + 0.4	6/14/79	96 ab	2,4-D + pic.	2.2 + 0.4	6/14/79	100
	2,4-D	2.2	6/14/79	96 ab	2,4-D	2.2	6/14/79	100

[1]Where abbreviated, picloram = pic.; dicamba = dic. Mortality figures in column followed by the same letter are not significantly different at the P = 0.1 level of confidence as determined by Duncan's multiple range test. No letters indicate no significant differences. Trials 1-7 from Nevada, 8 from California.

[2]The plot was initially sprayed with 3.4 kg/ha 2,4-D, June 25, 1977.

[3]RB = rotobeat; IS = initially sprayed with 2.2 kg/ha 2,4-D, June 16, 1977.

Other herbicide treatments that resulted in similar salt rabbitbrush control were: (a) 3 lb/acre (3.4 kg/ha) triclopyr ester applied June 14, (b) 3 lb/acre (3.4 kg/ha) 2,4-D applied in June, and (c) 2,4-D plus dicamba plus picloram (4:4:1 w/w/w) at 1 lb/acre (1.1 kg/ha) applied June 1. Generally, salt rabbitbrush was easier to control than greasewood (tables 2,3,4).

Foliar-applied herbicides were generally more effective than soil-applied herbicides for brush control. Dicamba granules applied at 2 lb/acre (2.2 kg/ha) in March controlled 91 percent of the salt rabbitbrush in trial 7 (table 2), but no soil herbicides controlled more than 27 percent of the greasewood. The permeability of the soil in the experimental area is very slow (Summerfield and Bagley 1974; U.S. Department of Agriculture, Soil Conservation Service 1978), which may account for the relative ineffectiveness of the soil-applied herbicides.

Rotobeating alone only killed 11 and 17 percent of the greasewood and salt rabbitbrush, respectively. Many shrubs resprouted vigorously the year following rotobeating or spraying with a herbicide which had resulted in poor control. Roundy and others (1980) showed that greasewood growth was accelerated the following year on shrubs sprayed with herbicides but not killed. They hypothesized that respraying greasewood a second season would greatly enhance brush mortality because of the increased growth rate of the new shoots of surviving plants. Results from trial 5 support this theory (table 2). Trial 5 was initially sprayed with 3 lb/acre (3.4 kg/ha) 2,4-D in June 1977. Only 30 percent of the greasewood was killed. It was resprayed with 1, 2 and 3 lb/acre (1.1, 2.2, and 3.4 kg/ha) 2,4-D in June 1978. The 3 lb/acre (3.4 kg/ha) rate applied in mid-June killed all of the remaining greasewood, indicating much better control.

Available soil moisture at time of herbicide application greatly affected control of greasewood and salt rabbitbrush. Trial 8 was a very wet site in northeastern California which received tail water from irrigated fields (U.S. Department of Agriculture, Soil Conservation Service 1978). Greasewood and salt rabbitbrush control averaged 98 percent with all herbicide treatments (table 2). At the Gund Ranch, trial 2 was a fairly mesic site during the year of herbicide application, whereas trial 3 was a xeric site. Soil water potentials at 18 inches (45 cm) averaged -0.07 and -2 M pascals on trials 2 and 3, respectively, during the herbicide application period. As a result, the total leader growth and growth rate of both greasewood and salt rabbitbrush was less in trial 3 than trial 2 (fig. 1). This translated into significantly (P = 0.1) lower greasewood control in trial 3. Maximum brush control achieved was 94 and 58 percent for greasewood and 100 and 90 percent for salt rabbitbrush in trials 2 and 3, respectively (table 2).

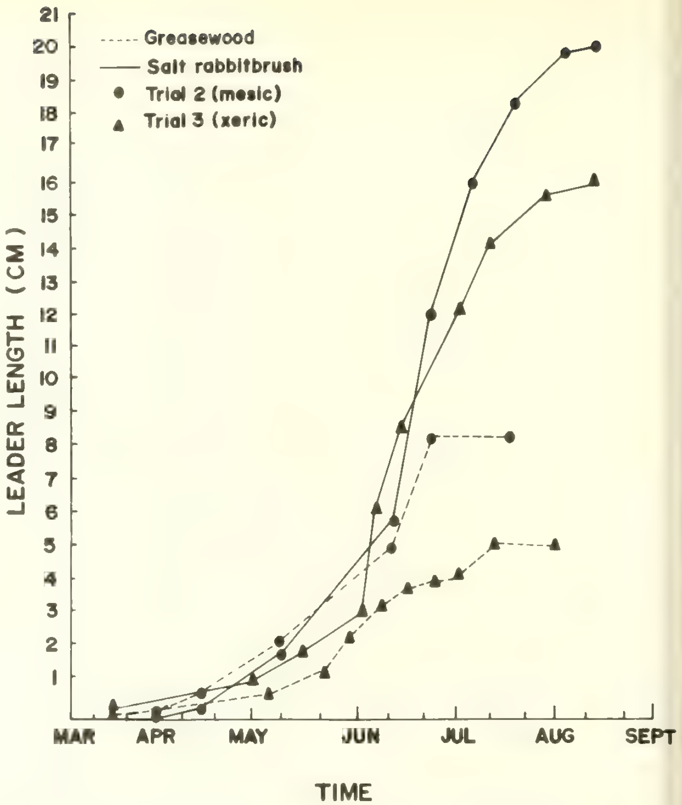

Figure 1.--Leader length (cm) of greasewood and salt rabbitbrush in mesic trial 2 and xeric trial 3

There was a trend toward greater brush control with higher rates of 2,4-D in the xeric trial, but not in the mesic trial. This probably resulted because of the poor greasewood control on xeric trial 3, consequently most of the brush mortality was salt rabbitbrush in that trial (table 4).

Control of greasewood was more affected by xeric conditions than control of salt rabbitbrush. In mesic trial 2, average greasewood mortality was 39 percent and salt rabbitbrush mortality was 52 percent. In more xeric trial 3, greasewood and salt rabbitbrush mortality averaged 10 and 53 percent, respectively (table 4). Greasewood control was reduced almost 30 percent because of xeric conditions, whereas salt rabbitbrush was not affected (P = 0.1).

Timing of herbicide application was an important factor in obtaining good brush control. In general best control of greasewood and salt rabbitbrush was obtained when herbicides were applied sometime from the last of May through June (table 3). The overlap in the accelerated growth phases of greasewood and salt rabbitbrush in some years is from the last week of May to mid-June (Roundy and others 1980). Accelerated growth as used here means a growth rate of new shoots of at least 0.04 inch per day (1 mm/day). This period correlates well with the dates of herbicide application that resulted in the highest brush mortality (table 3).

Table 3.--Response of greasewood and salt rabbitbrush (percent brush mortality) to herbicide application in trials conducted in central Nevada[1].

Trial	May 4	May 12	May 17	May 22	June 1	June 7	June 14	June 21	June 28	July 11	July 27	August 1
	Percent											
1												
Greasewood		36d			71a			66ab		62ac	47cd	
Salt rabbitbrush		39ef			96a			90a		55ce	47df	
2												
Greasewood	35bc		18c				84a		25bc			
Salt rabbitbrush	44b		17c				69a		69a			
3												
Greasewood	2b		6ab			20ab	29a		3b	2b		
Salt rabbitbrush	59a		48b			53ab	62a		64a	61a		
4												
Greasewood								95a	81b			
Salt rabbitbrush								89a	50b			
5												
Greasewood							95a	92ab	90ab			
Salt rabbitbrush							91a	88a	76b			
7												
Greasewood				65a	55ab				50ab	50ab		39b
Salt rabbitbrush				60ab	78a				60ab	47ab		39b

[1]Row means followed by the same letter are not significantly different at the P = 0.1 level of confidence as determined by Duncan's multiple range test.

Table 4.--Comparison of effectiveness of brush control with 2,4-D in mesic trial 2 and xeric trial 3 in a typical greasewood-salt rabbitbrush community in central Nevada[1].

	Brush mortality (%)						
	Date Month/day				Rate Kg/ha		
Trial	5/4	5/17	6/14	6/28	1.1	2.2	3.4
2 (mesic)							
Salt rabbitbrush	44ee	17fh	77a	69ab	54ab	48ac	53ab
Greasewood	35df	18fh	76a	25eg	39bc	34c	43bc
3 (xeric)							
Salt rabbitbrush	34df	50bd	62ac	64ab	42bc	55ab	61a
Greasewood	2h	6gh	29ef	3h	7d	13d	10d

[1]Row and column means of each variable (rate and date) followed by the same letter are not significantly different at the P = 0.1 level of probability as determined by Duncan's multiple range test.

The date of herbicide application which resulted in the highest simultaneous control of greasewood and salt rabbitbrush in trials 2 and 3 was June 14 (table 4). This correlated with times of accelerated growth for salt rabbitbrush in trials 2 and 3 and for greasewood in trial 2. Greasewood in trial 3 never exhibited an accelerated growth phase which may account for the low mortality of greasewood in that trial (fig. 1; table 4). Greasewood does not obtain the leader lengths of salt rabbitbrush (Roundy and others 1980) (fig. 1). This is one reason why greasewood is generally

harder to kill than salt rabbitbrush. If all other factors are equal, greasewood does not have the herbicide-absorbing area of salt rabbitbrush. Greasewood also exhibited a shorter time span than salt rabbitbrush in which optimum control could be obtained (table 3). This is probably because greasewood starts accelerated growth in late May with salt rabbitbrush, but ceases by July, whereas salt rabbitbrush continues until August (Roundy and others 1980).

In contrast to other reports (Hyder and others 1958; Mohan 1973), 3 to 4 inches (8 to 10 cm) of leader length may not be necessary to obtain good rabbitbrush control. The salt rabbitbrush in trials 2 and 3 did not attain that leader length until around June 10 (fig. 1). There were two spray dates before June 10 and two spray dates after June 10. Salt rabbitbrush control averaged 27 and 50 percent in trial 2, and 41 and 63 percent in trial 3 before and after June 10, respectively. These results indicate that brush mortality was higher after leader length exceeded 3 inches (8 cm). However, leader growth rate was also greater after June 10 so this could account for greater brush mortality. Herbicide applications in August did not control more than 40 percent of the salt rabbitbrush (table 3), yet average leader length exceeded 3 inches (8 cm). In trial 1 best control of salt rabbitbrush (96 percent) was obtained when 2,4-D was applied on June 1 when average leader length was only 1.5 inches (4 cm). An average leader length of 1.5 inches (4 cm) indicates that accelerated growth of salt rabbitbrush is under way. First opening of the flower buds is correlated with growth cessation (Roundy and others 1980). Foliar herbicides should be applied to salt rabbitbrush after the average leader length reaches 1.5 inches (4 cm) and before first opening of flower buds in order to achieve optimum control.

Based on results of this study, the brush control treatment with the highest probability of achieving optimum, simultaneous control of greasewood and salt rabbitbrush is 2 lb/acre (2.2 kg/ha) 2,4-D or 2 lb/acre (2.2 kg/ha) 2,4-D plus 0.5 lb/acre (0.6 kg/ha) picloram applied as a foliar spray sometime from the last of May through June. The addition of 0.5 lb/acre (0.6 kg/ha) picloram increased brush mortality ($P = 0.1$) in some trials (table 2). Under xeric conditions, such as in trial 3, it might be necessary to spray in two consecutive years to achieve good brush control.

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ATRIPLEX/GRASS AND FORB RELATIONSHIPS UNDER NO GRAZING AND SHIFTING PRECIPITATION PATTERNS IN NORTH-CENTRAL WYOMING

Herbert G. Fisser and Linda A. Joyce

ABSTRACT: Analysis of long-term vegetation records on three saltbush (Atriplex gardneri [Moq.] D. Dietr.) exclosure sites in the Big Horn Basin of Wyoming demonstrated significant changes in community composition. Within a total community responsive only to precipitation, there was a simultaneous increase in grasses and decrease in shrubs. Seasonal precipitation was also changing during the 1963 to 1978 period, with decreases in spring precipitation and increases in winter precipitation. Analyses of the relationship between precipitation and standing crop demonstrated that this relationship was significantly affected by the changing community dynamics. The response of the saltbush community to precipitation dynamics was much greater when the herbaceous component was more than 50 percent of the total standing crop. Greatest water use efficiency was demonstrated when community components strongly shifted toward herbaceous species.

INTRODUCTION

Climate/vegetation relationships have long been of interest in the semi-arid regions of the western United States (Craddock and Forsling 1938; Smoliak 1956; Wight and Hanks 1981). Wide weather fluctuations and the resultant variability in vegetation production have large impacts on animal production. Understanding the long-term relationships between weather and forage availability could provide valuable interpretive tools for the management of these lands.

The objectives of this paper were to: (1) document a 25-year grazing and research program in the Big Horn Basin; (2) investigate the vegetation response of low condition range to protection from grazing; and (3) quantitatively describe standing crop and precipitation relationships of the saltbush community.

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REGIONAL HISTORY AND ECOLOGICAL RESEARCH

The Big Horn Basin comprises some 8 million acres (3.2 million ha) in north-central Wyoming. Much of the area is classified in the 5-to 9-inch (13-to 23-cm) annual precipitation zone by the Soil Conservation Service (1966). Precipitation levels increase near the mountains (Shrader 1978). Chenopod vegetation, including greasewood (Sarcobatus vermiculatus [Hook.] Torr.), winterfat (Ceratoides lanata [Pursh] J. T. Howell), and hopsage (Grayia spinosa [Hook.] Moq.), occurs in large expanses and provides a base for winter livestock grazing (Bindschadler 1948; Fisser and others 1979). The most common chenopod of the Big Horn Basin is Gardner saltbush (Atriplex gardneri [Moq.] D. Diet.). It occurs on areas of poorly developed alkaline, often sodic, and usually silty soils (Vosler 1962). Low winter snow cover in the Basin provides ideal winter sheep grazing (King 1959; Shrader 1978).

Important climatic differences exist between the Big Horn Basin and similar grazing areas west of the Continental Divide. The similarities are obvious: saline soil, low precipitation, warm summer temperatures, and cold winters. Dissimilarities involve a relatively even distribution of precipitation in the Great Basin compared to a concentration of moisture during late spring in the Big Horn Basin. Associated with spring moisture is a later but very accelerated warm-up which, in the Big Horn Basin, produces a climate unlike the semi-mediterranean climate of the Great Basin (Daubenmire 1968).

From the late 1880's into the 1920's vast herds of sheep and cattle indiscriminately utilized the Big Horn Basin (Duhig 1948). Excessive and continuous use severely depleted perennial vegetation, similar to the impacts on winter rangeland grazing areas in Idaho and Utah (Frink 1954).

With the introduction and terrifying epidemic explosion of halogeton (Halogeton glomeratus (C. A. Mey. in Ledeb.) in the 1930's (Palmer 1955), a contagious hysteria gripped the West including Wyoming's Little Colorado and Red Desert areas, and the Big Horn Basin (Erickson and others 1951; Cook and Stoddard 1953; Sharp 1954; Bohmont and others 1955). The image of rangelands totally dominated by the annual invader and the

possibility of losses of thousands of livestock overnight all sparked a revolution of concern for arid lands, especially in Wyoming (Rauchfuss and others 1957; Morton and others 1959; Bruner and Robertson 1963). The Bureau of Land Management was allocated many millions of dollars to find ways to eradicate and destroy the exotic invader. A few can yet recall the rather senseless chemical spray control activities (Palmer and others 1955). Reason did prevail, however, and ecologically oriented research was developed by such leaders as Larry Stoddard and Wayne Cook in Utah, Joe Robertson in Nevada, and Ed Tisdale and Lee Sharp in Idaho (Frischknecht 1967).

DRY CREEK GRAZING INTENSITY STUDY

Grazing Study Origin and Methodology

When halogeton was found in the Big Horn Basin, funding by the Department of the Interior was quickly allocated to initiate ecological evaluation and conduct grazing intensity studies. The University of Wyoming with Alan Beetle, Bob Lang, and Dixie Smith then entered the fray. The Dry Creek Halogeton Pasture Study near Greybull was initiated in 1956 (fig. 1). Some may even recall the BLM-sponsored range weed control tour to that grazing unit during the summer of 1961. The group observed vegetation response to protection from grazing and to three levels of winter utilization intensity, 20, 40, and 80 percent removal of saltbush annual production. At that time, after five years of controlled grazing, data were inconclusive, with greater variation exhibited among pastures of similar use than those of dissimilar use. To alleviate the problem, grazing and vegetation sampling procedures were modified. A band of 1,800 ewes was obtained instead of the previous 200, vegetation sampling was stratified to include only saltbush vegetation, and an additional pair of pastures with an allocated 30 percent saltbush removal rate was attained by division of the existing 20 percent removal units (fig. 2) (Fisser and Wight 1965).

Area cover, herbage production, and precipitation were measured at each exclosure. Twenty 1-foot by 10-foot (0.3-m x 3.0-m) plots were located systematically along a randomly located 100-foot (30-m) steel tape. Each plot was subsampled for vegetative cover using 10 1-foot by 1-foot (30-cm x 30 cm) subplots. Percent area cover of all herbaceous semiwoody and woody species was estimated within each subplot. Standing crop was determined by clipping herbaceous species at ground or crown level at approximately peak community standing crop each year. Saltbush was treated as a herbaceous species with new growth clipped at the sampling time. All clippings were oven-dried at 160°F (70°C) for 24 hours prior to weighing.

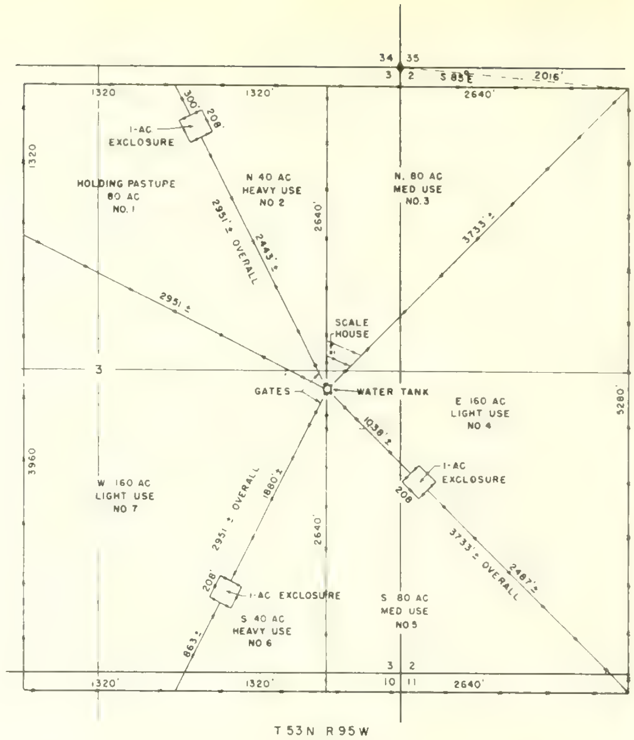

Figure 1.--The 640-acre Dry Creek Halogeton Research Pasture system which was constructed in 1955 and located 10 miles Northeast of Greybull, Wyo., in the Big Horn Basin (dimensions 1 mile by 1 mile).

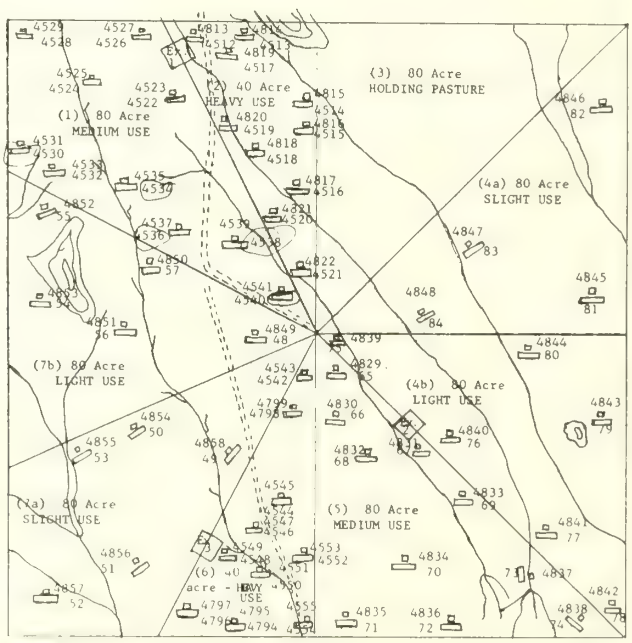

Figure 2.--Dry Creek Halogeton Pasture system showing the modified fencing for the 30 percent saltbush utilization pastures and locations of permanent quadrats for shrub mapping (2 ft by 20 ft) and herbaceous cover (4 ft by 4 ft) by point hit procedures.

Precipitation was recorded on site four times a year with simple aluminum rain gauges: April 15, July 1, September 1, and October 15. Oil was added after each reading to prevent evaporation, and during the winter months antifreeze was added in known amounts to prevent the gauges from freezing and breaking.

Grazing Study Summary

In 1956 and 1957, within the 640-acre (260-ha) unit, halogeton occurred only in small areas at the locations shown in black in figure 3. By 1960 halogeton was distributed over all the pastures (fig. 4) and by 1965 its abundance was clearly shown to be related to grazing intensity (table 1 and fig. 4) (Fisser and others 1966). In 1967, the grazing study was terminated since it was patently obvious, as noted by others (Frischknecht 1967; James and Cronin 1974), that halogeton was disturbance-dependent. Even with total native vegetation cover of only 10 to 13 percent, essentially all contributed by Gardner saltbush, the exotic annual was unable to invade in amounts adequate to pose a threat to the ecological systems, or to the grazing animals when the saltbush was grazed at slight to moderate stocking levels (Fisser and Steger 1967). Significant response of Gardner saltbush to differential grazing intensity was apparent. Interpretive evaluation of winter grazing stress suggested that 35 percent saltbush removal was acceptable for maintenance of the shrub populations (fig. 5). Halogeton populations in the exclosures were similar to those of the slight-use pastures with a density of less than two plants per square foot. Abundance was almost eight times greater in the heavy-use (80 percent) pastures (table 1).

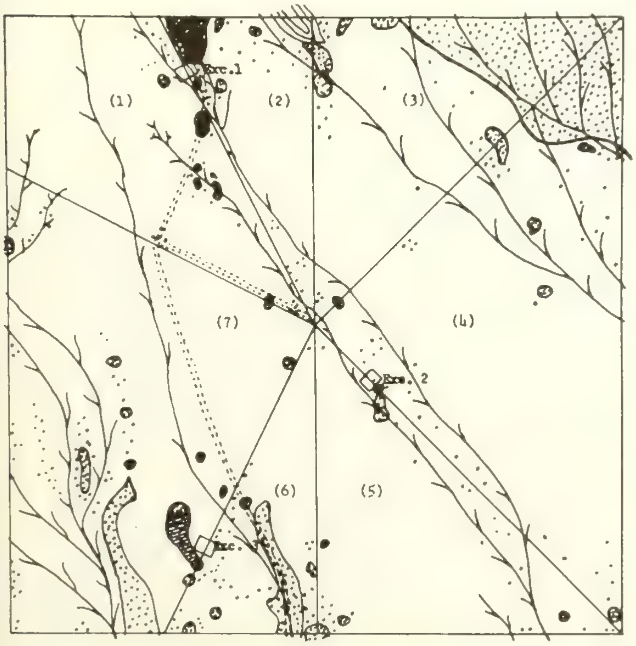

Figure 3.--Distribution of halogeton within the Dry Creek Halogeton Pastures during 1956-1957.

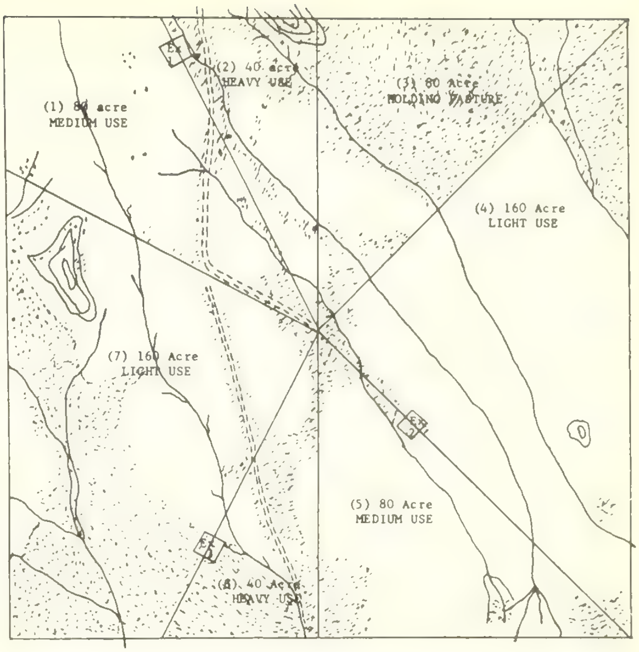

Figure 4.--Distribution of halogeton within the Dry Creek Halogeton Pastures during 1960.

Table 1.--Density of halogeton in 1964 and 1965 as related to grazing utilization intensity.

Intensity of use	Average no. of plants per square foot 1964	1965
Slight (20 percent)	1.0	1.7
Light (30 percent)	1.8	2.4
Moderate (40 percent)	2.0	3.1
Heavy (80 percent)	7.5	13.3

During the 1962 field season, the Arid Land Ecology Research Program was expanded to monitor exclosure vegetation in a wide variety of vegetation types in Wyoming. The objectives of the monitoring program were multiple; the sampling scheme was the same one used in the halogeton study in Dry Creek (Fisser and Hamner 1963). Study of the exclosure vegetation continued beyond the termination of the grazing study in 1967, annually through 1983.

Figure 5.--Compare the uniform texture apparent in the heavy use (80 percent) pasture to the slight use (20 percent) pasture to the left, exclosure 3 on the fence line, and the open native range in the foreground. This 1966 oblique aerial photograph of the Dry Creek Grazing Intensity pastures shows the results of severe overuse of Gardner saltbush.

VEGETATION/PRECIPITATION INTERPRETIVE ANALYSES

Methods

Standing crop and precipitation data were monitored inside the exclosures over the 1963 to 1983 period. Field collection is still ongoing. For this study, only 1963 to 1978 data were used. Standing crop data were summarized into plant groups on an annual basis from the original field sheets and the annual reports of the Arid Land Ecology Research Program (Fisser and others 1980).

Long-term records of annual precipitation were obtained from the nearby U.S. Weather Station at Basin, Wyo., to determine if the climate was undergoing any significant long-term wet or dry cycles. The period 1940 to 1978 was used and a 7-year moving average was compiled to smooth annual variation. For purposes of comparison, the onsite seasonal precipitation and standing crop data were also smoothed using a 7-year moving average.

Analyses

Several analyses were made with the onsite data. To determine whether vegetation compositional changes were occurring, an index of vegetation composition was calculated by dividing grass and forb standing crop by total standing crop each year at each site. If grass and forb standing crop were increasing either from protection from grazing or climate changes, the index would increase. If no changes were occurring, the index would fluctuate randomly or with seasonal precipitation.

The long-term relationship between seasonal precipitation and standing crop was examined using correlation analysis. As the entire community was sampled, the relationship of plant groups within the community and precipitation could also be examined.

RESULTS AND DISCUSSION

Vegetation Dynamics

In 1963, standing crop was still predominantly Gardner saltbush, even after 7 years of protection from grazing (table 2) (Fisser and Hamner 1963). Grass was very sparse and only in exclosure #1 were forbs composing 8 percent of the standing crops, a significant component. The grass species present in the exclosures were bottlebrush squirreltail (Sitanion hystrix [Nutt] J. G. Sm.) and Sandberg bluegrass (Poa secunda [Presl]). The absence of associated species in the wet year of 1964 can be noted from the photograph of exclosure 2 (fig. 6).

Table 2.--Percent biomass composition inside halogeton exclosures in 1963 and 1979.

Exclosure	1963			1979		
	Grass	Forb	ATGA[1]	Grass	Forb	ATGA
1	1	8	91	34	4	62
2	<1	1	98	51	1	48
3	<1	1	99	46	5	49

[1] ATGA = Atriplex gardneri

Figure 6.--Gardner saltbush vegetation inside exclosure 2 at time of herbage production sampling in 1964. Note almost total monoculture dominance by saltbush.

Sixteen years later, in 1979, a significant change in community composition was apparent (table 2) (Fisser and others 1980). Grass standing crop constituted 34, 51, and 46 percent of total standing crop in exclosures 1, 2, and 3, respectively. Gardner saltbush reflected this increase in grass standing crop by decreasing to 62, 48, and 49 percent of the total standing crop (fig. 7). Forb standing crop remained a small component of the community. The species of grass present in the exclosures after sixteen years of protection were the same species recorded in 1963. Annual and perennial forb species did increase in total numbers although the standing crop remained very small. Thus, the increase in grass standing crop represents an increase in the same species found in 1963 rather than an increase in the diversity of grass species found at these exclosures.

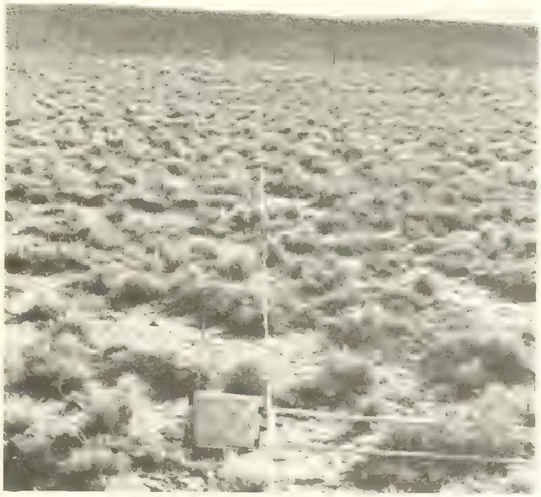

Figure 7.--Mixed grass (bottlebrush squirreltail) and shrub (Gardner saltbush) inside exclosure 2 in 1979.

The change in community composition was seen in the steady increase of the index of vegetation composition at each exclosure (fig. 8).

A steady change in the dynamics of total standing crop would affect the results of this index. In this study, however, the annual herbage production fluctuations were large. Total standing crop was, consequently, not significantly correlated with time, but was significantly correlated with precipitation ($r = .67$). No consistent increase associated with protection from grazing was found. Thus, the index of vegetation composition expressed the shifting changes in those intracommunity compositional dynamics.

Differences in the pattern of the community index among exclosures reflect soil and topographic differences (fig. 8). Exclosure 1 was the least productive because of limiting soils and it exhibited the longest delayed increase of the index of vegetation. Exclosure 3 was most typical of the Big Horn Basin's vast areas of silty soils and little relief. Exclosure 2 was a silty site which often received runon water. The index for that site demonstrated the earliest, greatest, and most dynamic increase.

Precipitation Dynamics

Precipitation was not recorded at the halogeton exclosures until 1960. For comparative purposes, the annual precipitation records for 1940 through 1982 from the nearby U.S. Weather Station at Basin, Wyo., were smoothed by application of a 7-year moving average (fig. 9). Annual precipitation records from Basin reflected a dry period during the 1950's and increased annual moisture into the mid-1960's. The Dry Creek halogeton grazing intensity studies thus were initiated near the time that annual precipitation began an increasing trend. A decreasing trend during the late 1960's and early 1970's is also apparent (fig. 9). Inspection of annual precipitation values recorded at the Dry Creek Pastures during the 1960's reveals trends similar to those noted at Basin, Wyo.

By segregating seasonal moisture values at the exclosures in the grazing intensity pastures, seasonal trends were found. While the annual change was downward, winter precipitation increased greatly and the combined values for summer and fall also increased (fig. 10). The downward trend of total annual precipitation thus occurred as a result of decreasing spring precipitation, the largest individual moisture component contributing to total annual precipitation at these sites.

Vegetation/Precipitation Interaction

Vegetation portrays the biotic response environmental factors. In semiarid regions, soil, precipitation, and temperature can readily be identified as controlling influences. Successional changes in the arid regions are slow. Previous research has shown that climatic effects usually dominate vegetation dynamics and rates of change that are induced by management effects (Reed and Peterson 1961; Hastings and Turner 1965; Lewis and others 1965).

At the Dry Creek grazing intensity pastures, seasonal precipitation trends were reflected by the changing dynamics of the plant community. The consistent increase in the community index reflected a similar increase in the 7-year moving average of grass and forb standing crop and the concomitant decrease in the shrub component. Using the 7-year moving average for comparison, shrubs decreased over the period 1963 through 1971 and grasses and forbs increased (fig. 10).

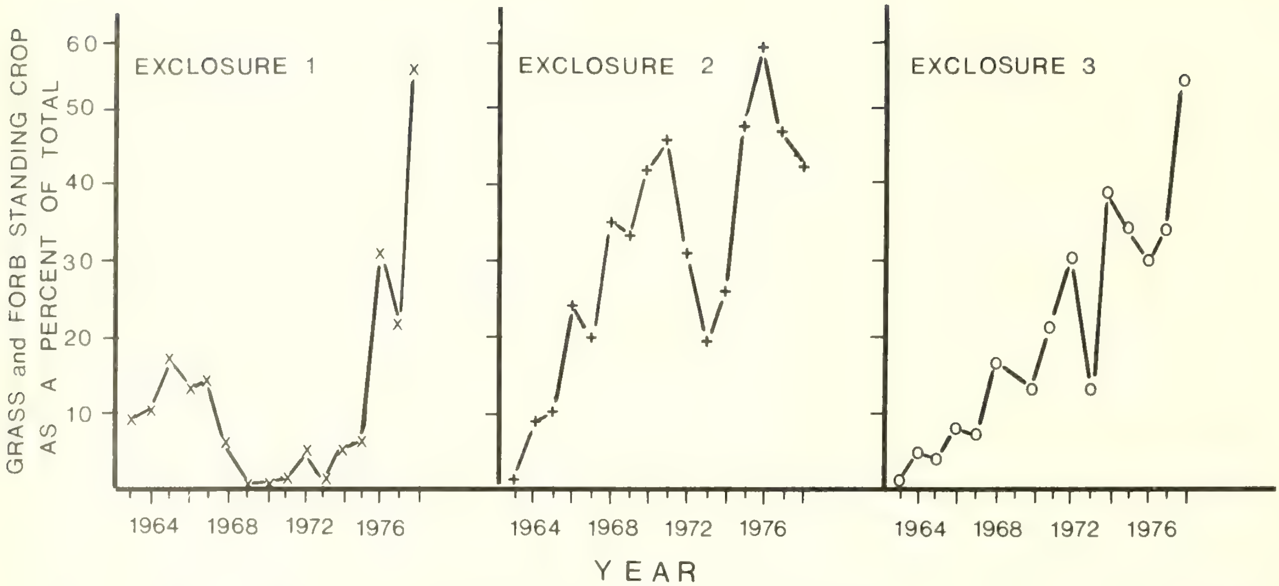

Figure 8.--Community index at saltbush sites in Wyoming. This index is the ratio of grass and forb standing crop to total standing crop.

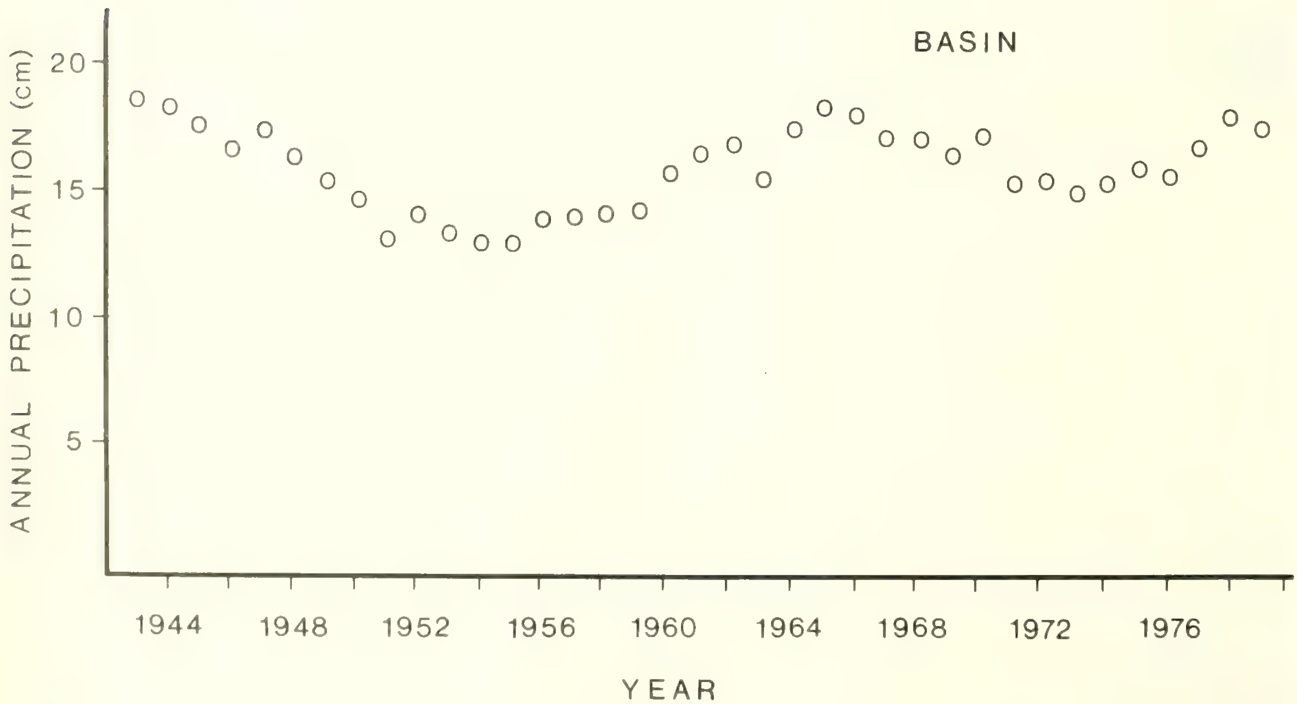

Figure 9.--Smoothed 7-year averages from 1940 through 1980 of annual precipitation at the Basin, Wyo., U.S. Weather Service Station.

Total standing crop, reflecting the declining dominance of saltbush, decreased through 1971. Saltbush continued to decrease during subsequent years in conjunction with the increases of grasses and forbs (fig. 10). Trends shown for halogeton exclosure 2 were representative of all. Each of these sites was released from grazing in the mid 1950's. Community composition changes thus appear to have been most strongly influenced by protection from grazing during the early years. With condition class improvement through the 1960's, dynamic response to annual precipitation variation became increasingly evident (fig. 10).

Long-term Relationships

Based on analysis of data from seven saltbush exclosures in the Big Horn Basin, including the halogeton sites, individual plant groups were correlated with different precipitation periods (Joyce 1981). Grass and forb standing crop was significantly correlated with winter precipitation; shrubs were significantly correlated with spring precipitation at each site (table 3). In addition, grass and forb standing crop tended not to be correlated with spring precipitation. Similarly, shrubs were not correlated with winter precipitation. These plant groups exhibited temporal separation in terms of precipitation dependence.

No plant group was correlated with the previous fall's precipitation. The correlation coefficients, while not significant, did consistently have a negative sign, however, indicating a possible negative relationship between the previous fall's precipitation and shrub standing crop. This contrasted with the findings of Blaisdell (1958) and may well represent variations attributable to the regional climatic differences noted previously. Total standing crop was significantly correlated with spring precipitation and with the sum of winter and spring precipitation, reflecting the composite results of the individual plant group analyses.

These correlation patterns reflected seasonal precipitation trends. Increasing grass and forb standing crop was correlated with winter plus spring precipitation which was also increasing (fig. 11). It may be that spring moisture was not available for use by the early maturing bottlebush squirreltail and sandberg bluegrass and that the changing patterns in seasonal precipitation benefited the winter precipitation dependent grasses, but put at a disadvantage the spring precipitation dependent shrubs.

Long-term records of exclosures such as these have often been used to develop predictive equations for range forage (Smoliak 1956) or to assess water use efficiency on grasslands and shrublands (Webb and others 1978). Community composition shifts are often not accounted for in these equations of total standing crop. The index of vegetation composition demonstrated a steady increase at each exclosure, although the pattern varied (fig. 8). At exclosure 2, the index increased steadily, decreased in a dry year, and fluctuated in the remaining years. If the first segment represents a continual shift, irrespective of fluctuations in total standing crop, then the break could indicate a stabilization of the intra-community dynamics. To test this theory, the entire time span was divided into two periods: 1963 through 1971 and 1972 through 1978. The relationship between standing crop and seasonal precipitation was examined within each time period at exclosure 2.

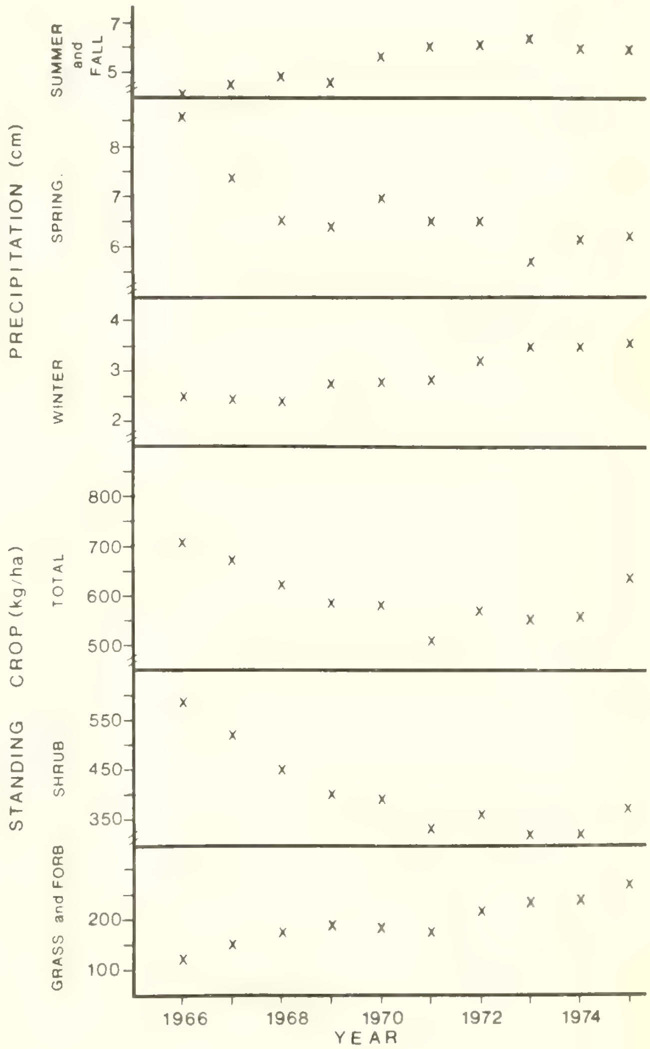

Figure 10.--Smoothed 7-year moving averages of seasonal precipitation and standing crop at halogeton exclosure 2 for 1964 through 1978, respectively.

Table 3.--General pattern of relationship between precipitation distribution and standing crop inside saltbush exclosures.

Precipitation	Vegetation component: Grass and forb	Shrub	Total
Fall	NS[1]	NS	NS
Winter	+[2]	NS	NS
Spring	NS	+	+
Winter plus spring	NS	+	+

[1] NS - not significant

[2] + - significant $p \leq .05$

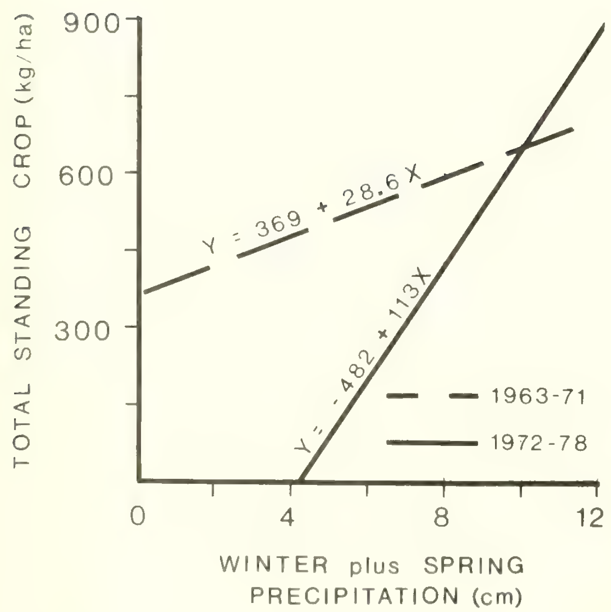

Figure 11.--Regression lines during and after vegetation composition changes at halogeton exclosure 2. The line for 1963-71 represents inefficient water use by the predominantly Gardner saltbush vegetation. The much more efficient water use of the mixed grass-shrub complex during the latter years is exhibited by the steeper regression line.

The two plant groups (grasses and forbs, and shrubs), were not significantly correlated with any season of precipitation during the first period (1963 through 1971), indicating that plant competition dominated intracommunity dynamics. This contrasted with the significant correlations in the analysis of the entire time period. Total standing crop, on the other hand, was significantly correlated with winter plus spring precipitation during this first period.

By 1971, the exclosures had been protected from grazing for 16 years, and the community dynamics during the 1972 to 1978 period appeared to be changing less than in the early period of 1963 to 1971. When the community shifts slowed down in this second period, the individual plant groups were significantly correlated with a period or periods of seasonal precipitation in the same manner as the results of the entire time period (table 3). Total standing crop was also significantly correlated with winter plus spring precipitation during the later period. Precipitation was once again the dominating influence on the plant community.

When the regressions for total standing crop in each period were compared, the total standing crop increase per unit of spring moisture was much less responsive during the early period than during the later period (fig. 10). The very steep regression slope for the later period suggests a greater water use efficiency of mixed herbaceous and shrubby vegetation as compared to that of the predominately shrubby vegetation during the earlier period. Grass and forb standing crop prior to 1972 comprised 25 percent of the total average standing crop. From 1972 through 1978, this value attained a seven year mean of 50 percent of the total standing crop. The slopes of the lines shown in figure 10 are significantly different.

The results of these regression analyses indicate that changing community dynamics, exhibited by condition class improvement increase of the present data, can significantly affect the relationship between precipitation and standing crop. Regression analyses of long-term vegetation data have been continually fraught with large variability. A careful analysis of this variability could lead to a more significant understanding of the vegetation-precipitation relationship.

SUMMARY

The Big Horn Basin is a vast semi-arid part of north-central Wyoming. Although vegetation and climate are similar to comparable areas of Idaho and Utah, west of the Continental Divide, important differences exist in temperature and moisture characteristics, including delayed initiation but accelerated spring warmup, and moisture concentrated during the growing season.

Funding and research to combat invasion by halogeton were initiated in the mid-1950's. In addition to the establishment of livestock-proof exclosures throughout western Wyoming, the Dry Creek Grazing Intensity Study was initiated in 1956 to determine Gardner saltbush response to different intensities of winter utilization by sheep and to determine the related invasion potential of halogeton. By 1967 it was evident that a winter utilization rate of 35 percent of annual herbage production was acceptable and actually desired in order to stimulate plant and root growth. Halogeton abundance was very specifically disturbance and grazing intensity related. By the late 1960's when improved condition class of the grazing unit vegetation became evident, there was also a comparable halogeton reduction. Where intensive livestock disturbance continued, halogeton abundance was maintained.

The primary analytic intent of this paper was the identification and evaluation of long-term herbage production response to precipitation dynamics in conjunction with long-term protection from the stress of livestock grazing.

The exclosures were constructed on sites where the plant community appeared to have had many years of continuous overuse. Almost total elimination of perennial grasses and forbs had occurred and reduced vigor of Gardner saltbush was evident. Vegetation, from 1955 through 1971, exhibited population changes suggestive primarily of recovery from many years of continuous overuse. During this period grass and forb production was minimal, but increasing.

Data from 1972 through 1978, however, portrayed increasing grass and forb production with corresponding decreasing shrub production. In 1978, after 23 years of protection, grass contributed nearly 50 percent of the standing crop. In contrast, it contributed less than 1 percent after 7 years of protection in 1963.

The results of this study have shown that the vegetation composition of three saltbush exclosures changed significantly under protection from grazing. Additionally, these changes occurred during a time when seasonal precipitation was also changing. Spring precipitation was decreasing and winter precipitation increasing. Analyses of the relationship between precipitation and standing crop, based on the entire period, would have been misleading. It was demonstrated that the changing plant composition affected the relationship of total standing crop to precipitation. During the earlier period, while total herbage production was primarily from saltbush, response to moisture in terms of lb/acre for inch (kg/ha for 1 cm) of precipitation was minimal. During the later period, however, with recovery from historical overuse essentially complete, and herbaceous species contributing as much as one half or more of the total vegetation production, response to precipitation was much more dynamic.

Protection from grazing was only partially responsible for the vegetation trends. The shift of seasonal precipitation, from predominance during spring to greater abundance during winter, became more important through time. Interpretation of climatic-vegetation relations based principally on early short-term records, would have suggested a misleading response to nongrazing. The longer term records, however, provided the opportunity to isolate early responses as recovery from historical overuse. In addition, the total data set afforded comprehensive study of vegetation changes as well as greater definitive capability for prediction of climatic/management interrelationships.

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MOISTURE STRESS, ATRIPLEX SPECIES, AND RECLAMATION AT BLACK MESA, ARIZONA

Scott D. Wilkins and Jeffrey M. Klopatek

ABSTRACT: The capacity of native shrubs to withstand extremely negative soil water potentials influences their ability to successfully colonize disturbed sites in the arid Southwest. Plant water potential measurements of *Atriplex canescens* growing on natural areas and reclaimed mine sites were compared to determine seasonal and diurnal patterns of moisture stress and internal water potential components. Soils on reclaimed sites were high in clay and significantly higher in electrical conductivity. *A. canescens* from natural sites had the greatest drought-resistance capacity.

INTRODUCTION

The increasing development of coal reserves in the Intermountain West has focused attention on the unique reclamation difficulties associated with arid lands. Under optimum conditions, normal secondary succession processes in the Four Corners area of Arizona can require from 30 to 50 years or longer before the ecosystem approaches a climax stage (Cook 1976). Seed germination and plant establishment in arid lands are often hindered by insufficient moisture availability during critical times of plant growth and development (Hodder 1977). This is due to unpredictable precipitation patterns, seasonal droughts, extreme temperature variability (seasonally and diurnally), and scanty vegetative cover. Moisture stress problems are further compounded by the altered site conditions brought on by mining and reclamation activities and the physical and chemical characteristics of the mining overburden itself.

Water availability can be restricted by increased runoff and evaporation due to the lack of established vegetative cover, "piping" (rapid percolation to depths beyond the root zone; Dixon 1982), and compaction by massive land-moving, surface-mining equipment (Hodder 1977). Indorante and others (1981) reported that, in comparison with undisturbed soils, newly constructed soils had high bulk densities, moderately fine texture, and lacked structure, resulting in compaction and poor aeration. Spoil material also tended to have higher pH, electrical conductivity (indicating increased salinity), and exchangeable sodium (Indorante and others 1981), characteristics that may result in less available soil moisture (Scholl 1982). Rai and others (1974) found that San Juan, N. Mex., shale mine spoils weathered rapidly to form a thin, fine-textured surface layer which considerably slowed down the reclamation process.

These findings stress the need for research that examines the adaptability of vegetative species that can withstand inhospitable conditions. The research presented in this paper analyzes the drought-resistance potential and adaptability of *Atriplex canescens* and other native shrubs by examining their moisture stress patterns on natural and disturbed sites.

STUDY SITES

The study sites were located at Black Mesa on the Hopi and Navajo Indian Reservations in northeastern Arizona. The mines are operated by the Peabody Coal Company. Black Mesa is a large (ca. 2,100,000-acre; 850 000-ha), heavily dissected highland with locally prominent mesas, canyons, and alluvial plains. The coal seams lie at the base of the Fruitland formation of late Cretaceous age (Packer and Aldon 1978). Soils are generally extensively eroded, poorly developed, and very low in organic matter (Thames and Verma 1975). Elevation ranges between 6,800- and 7,500-feet (2 100- and 2 300-m). Annual precipitation is unpredictable and seasonally distributed, averaging approximately 10- to 12-inches (25- to 30-cm). The precipitation pattern is bimodal, characterized by intense late summer (July to September) convectional thunderstorms and less frequent winter frontal systems. The temperature ranges annually from -15° F to 100° F (-27° C to 38° C).

A total of six sites were examined -- three natural and three reclaimed. Prior to mining

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activities, the reclaimed areas supported vegetation similar to the surrounding natural areas. Following reclamation, the disturbed areas were seeded with various native and nonnative grasses. The reclaimed sites differ in their edaphic characteristics. One is pre-Law (Surface Mining Control and Reclamation Act, 1977) with no topsoil. Two are post-Law; one of these has an extra layer of topsoil (to a depth of 10- to 12-inches; 20- to 25-cm).

The natural areas are characterized as Great Basin conifer woodland, interspersed with a mosaic of Great Basin desertscrub communities (Brown 1982). The uplands are dominated by pinyon-juniper woodland (Pinus edulis Engelm. - Juniperus osteosperma [Torr.] Little). Valleys and lowlands are dominated by scattered communities of rabbitbrush-snakeweed (Chrysothamnus spp. - Gutierrezia sarothrae [Pursh.] Britt. & Rusby), big sagebrush (Artemisia tridentata Nutt.), shadscale (Atriplex confertifolia [Torr. & Frem.] Wats.), fourwing saltbush (Atriplex canescens [Pursh.] Nutt.), and greasewood (Sarcobatus vermiculatus [Hook.] Torr.). Native grasses include galleta (Hilaria jamesii [Torr.] Benth.), blue grama (Bouteloua gracilis [H.B.K.] Lag.), Indian rice grass (Oryzopsis hymenoides [R. & S.] Ricker), and bottlebrush squirreltail (Sitanion hystrix [Nutt.] J.G. Sm.).

The predominant vegetation on the reclaimed sites consists of nonnative grasses, chiefly crested wheatgrass (Agropyron desertorum [Fisch.] Schult.), western wheatgrass (Agropyron smithii Rydb.), and smooth brome (Bromus inermis Leyss.), with scattered occurrences of fourwing saltbush, Russian thistle (Salsola kali L.), and Kochia species.

MATERIALS AND METHODS

Coleman soil moisture and temperature probes were buried at depths of 2-, 8-, and 20-inches (5-, 20-, and 50-cm) at three random locations on each of the six study sites. Soil temperature and resistance readings were measured using a combination soil moisture and temperature meter (Soil Test Model 300A). Concurrent air temperature and relative humidity readings were measured (using a sling-psychrometer) to correlate plant moisture stress with the vapor-pressure deficit of the atmosphere. Soil samples were taken from each site and analyzed for physical and chemical characteristics, including soil texture (Bouyoucos hydrometer method; Bouyoucos 1936), pH (with 0.01 M $CaCl_2$ solutions 1:1), electrical conductivity, and saturation percentage (U.S. Salinity Lab 1954; Black 1965).

Plant water potential measurements were taken in the field with a Scholander-type portable pressure chamber using nitrogen gas (Scholander and others 1965, 1966; Boyer 1967a; Waring and Cleary 1967; Tyree and Hammel 1972; Cline and Campbell 1976). Measurements were taken immediately preceding dawn to compare plants following the period of greatest soil moisture recharge and, therefore, the time of least plant moisture stress (Scholander 1966; Waring and Cleary 1967; Halvorson and Patten 1974; Branson and Shown 1975). Additionally, measurements were taken seasonally (September, January, March, and July) over 24-hour periods on both natural and reclaimed sites to compare the seasonal and diurnal patterns of plant moisture stress.

Water potential components were calculated using pressure-volume curves (Scholander and others 1965; Scholander 1966; Hellkvist and others 1974; Cheung 1975; Ladiges 1975; Hinckley and others 1980; Monson and Smith 1982). Excised fourwing saltbush (A. canescens) stems were immediately (<10-sec) placed under water, recut within 2-inches (5-cm) of the excised end, enclosed in a plastic bag, and allowed to reach full saturation (12- to 15-hours) (Scholander 1966; Boyer 1967b; Hellkvist and others 1974; Monson and Smith 1982; Hensen and others 1983). A modified pressure chamber was employed to allow the simultaneous testing of four stems of each species (Monson and Smith 1982). Four plants were placed in the pressure chamber with the cut ends slightly protruding. A Pasteur pipette filled with dry tissue paper was then placed over each stem to collect the liquid expressed at each pressure increment. Each pipette was weighed to within 3.53×10^{-6}-oz (0.1-mg) before and after each collection on an analytical balance (Mettler). Using the method outlined by Monson and Smith (1982), the pressure was progressively increased in 6.9-bar (0.69-MPa) increments to a maximum of 62.1-bars (6.21-MPa), each pressure acting as the balancing pressure of Scholander's method. The total volume of liquid expressed (V_e) from each sample was then added to the total sample fresh mass immediately following the analysis to obtain the original sample fresh mass (FM). Dry mass (DM) was determined after ovendrying for 48-hours at 221° F (105° C). The relative water content (RWC) was calculated from:

$$RWC = (FM - DM) - V_e / (FM - DM).$$

The internal water potential components were determined by extrapolation from pressure-volume curves using the equation (Tyree and Richter 1981; Monson and Smith 1982):

$$1/P = (V_o - V_e) / [RTN_s - F(V)],$$

where P = equilibrium balance point;

V_0 = symplastic water volume at full hydration;

V_e = volume of liquid expressed at that pressure;

R = universal gas constant;

T = Kelvin temperature;

N_s = total solute concentration in all cells;

F(V) = relation of turgor pressure to the volume of liquid remaining in all cells.

As V_e increases, 1/P decreases curvilinearly to the point of plasmolysis, due to decreases in the turgor pressure. Beyond plasmolysis (TLP = turgor loss point), turgor pressure drops to 0 and the relationship between 1/P and (V_0 - V_e) (the symplastic water volume) becomes linear, dependent only on changes in the osmotic potential. When this linear relationship is extrapolated back to the ordinate, it gives an estimate of the initial osmotic potential of the plant at full turgor. Additionally, turgor pressure can be estimated by subtracting the osmotic potential from the total plant water potential (Scholander 1966; Boyer 1967a, 1967b; Hellkvist and others 1974; Monson and Smith 1982).

RESULTS AND DISCUSSION

Soils

Comparisons of soil characteristics between the reclaimed and natural sites reveal no significant differences for pH or saturation percentage (Duncan's Multiple Range Test; table 1). However, the mean electrical conductivity measure (EC) was significantly higher ($p<0.01$) in the reclaimed sites than in the natural sites. This was especially evident at the 8- and 20-inch (20- and 50-cm) depths. Highest electrical conductivity was measured at the 20-inch (50-cm) depth at all sites, natural and disturbed, except for the post-Law reclaimed site. Since high soil solute levels significantly decrease soil water potential and increase plant water stress (Walter and Stadelmann 1974; Etherington 1982), this factor may substantially hinder plant establishment and revegetation efforts. It is important to note that the highest EC measurements on the reclaimed sites occurred below the topsoil layer (ca. 4- to 8-inches; 10- to 20-cm) in the overburden material. This would tend to emphasize the importance of topsoiling/topdressing reclaimed mine spoils at Black Mesa to increase the probability of revegetation success.

Table 1.--Selected soil parameters for the three reclaimed and three natural sites.[1]

Site	Depth	Sand	Silt	Clay	pH	EC[2]	Sat[3]
	in	percent				mmhos	%
Pre-Law	2	62.2	21.4	16.4	7.75	1.45	34.8
	8	69.6	16.0	14.4	7.70	1.10	32.9
	20	65.6	19.0	15.4	7.87	4.17	34.6
Post-Law	2	65.2	23.0	11.8	7.95	0.56	36.5
	8	56.2	17.0	16.8	7.90	2.12	43.5
	20	54.5	23.8	21.7	7.87	1.85	43.3
Extra topsoil	2	71.6	14.4	14.0	8.20	1.02	28.5
	8	78.6	11.0	10.4	8.25	2.49	27.6
	20	71.6	17.0	11.4	7.72	4.40	34.2
Saltbush	2	52.2	31.8	16.0	7.90	0.73	33.2
	8	37.0	38.6	24.4	7.85	.51	36.7
	20	53.6	31.4	15.0	7.87	1.06	37.0
Pinyon/juniper woodland	2	71.0	19.0	10.0	7.70	0.54	36.8
	8	69.0	16.0	15.0	7.80	.61	36.9
	20	48.0	24.0	28.0	8.00	.97	53.9
Rabbitbrush-snakeweed	2	77.0	20.0	3.0	7.60	0.43	34.1
	8	76.0	20.0	4.0	7.80	.44	37.1
	20	80.2	17.0	2.8	8.00	1.50	46.1

[1] Klopatek, J. M. Unpublished data on file at Tempe, AZ: Arizona State University, Department of Botany and Microbiology; 1983.

[2] Electrical conductivity.

[3] Saturation percentage = wt. water/soil dry wt.

These data appear to contradict other studies conducted at Black Mesa that report no differences in physical or chemical characteristics between the overburden and the undisturbed soils (Verma and Thames 1978). Suitable topsoil dressing (as defined by reclamation laws; Power 1978) is often taken from drainages on the specific mine cut. Several investigators have reported such alluvial deposits to be high in salt content (Branson and Shown 1975; Hodder 1977). This factor may increase salinity in the reclaimed topsoil and be important in limiting soil moisture uptake by plants during periods of reduced water availability (Louderbough and Potter 1982).

Atriplex canescens has been shown to be a halophyte, tolerating high salt conditions (Osmond and others 1980), and to have increased root and shoot growth in slightly saline conditions, compared to nonsaline conditions (Al-Jiburi 1972). Saltbush and other halophytic cold desert shrubs may be excellent colonizers of newly disturbed areas because of their ability to tolerate physiological water stress due to either dry or saline soil conditions. However, Al-Jiburi (1972) also noted that root and shoot growth of A. canescens was inversely related to the electrical conductivity of the soil solution above a certain threshold. Decrease in growth was noted at <7 mmhos. Since reclaimed soils have EC levels approaching this range, establishment of saltbush and other less salt-tolerant native species may be adversely affected.

Soils in the rabbitbrush-snakeweed community (table 1) show a significantly lower ($p<0.01$) percentage of clay in all horizons than any other community. This site was the driest, with very shallow soils containing a high percentage of rock. The low clay and high sand content may be important factors causing the soils to have a low moisture-holding capacity and increasing the moisture stress of plants growing on this site. The saltbush community, growing in a deep alluvial plain, shows significantly less sand than any other site.

Although not statistically significant, there seems to be a trend toward increasing pH and salinity with increasing depth in both the natural and reclaimed sites. The reclaimed site treated with an additional layer of topsoil has more sand, less silt and clay, lower saturation percentage, and higher pH and EC than the reclaimed sites with less topsoil. The high clay content found in all soils except the rabbitbrush community decreases the soil moisture potential.

Soil moisture resistance measurements indicate that, during periods of adequate precipitation, reclaimed soils have a higher relative water content than undisturbed soils, with two exceptions. During the winter when temperatures dropped below 14° to 19° F (-7° to -10° C) nightly, the natural sites contained more water. More important, the saltbush community soils contained more water than the extra-topsoil site at the 20-inch (50-cm) depth from August-December 1982. However, the pattern reversed from January-August 1983, with the saltbush soils becoming drier. On a total volume basis, the post-Law site (4- to 5-inches; 10-cm topsoil) contained the most moisture of the reclaimed soils, followed by the pre-Law site. The extra-topsoil site was the driest, especially at the 8- and 20-inch (20- and 50-cm) depths. There was no significant difference between the post-Law and the extra-topsoil sites at the 2-inch (5-cm) depth. The pre-Law (no topsoil) site was the wettest at this depth (containing the highest percentage of clay in the upper horizon of all reclaimed sites).

The saltbush community was the driest of the natural sites until the late summer (July) precipitation cycle began. However, it should be noted that these soil moisture comparisons were made during a period of above normal precipitation. During more typical seasonal droughts, the moisture-holding capacities or patterns of these soils may differ markedly. Additionally, some differences in soil moisture levels may be due to water use differences between the grass cover on the reclaimed sites and the shrub cover on the natural sites, or to the utilization of soil water in different horizons because of different rooting depths.

Plant Water Potential

Total plant water potential can be used as an estimate of the realistic soil moisture potential that the plant is experiencing in the rhizosphere and the accompanying internal water stress of the plant (Waring and Cleary 1967). Typically, internal water stress peaks at midday, stabilizes by midnight, and reaches a low before sunrise (Love and West 1972), allowing the plant to relieve its water deficit overnight. The data in table 2 allow a comparison of the mean predawn water potentials of Atriplex canescens on the five study sites during August 1982-March 1983 and April-August 1983. Water potential values correlate strongly both by study site and by area ($F = 13.62$, Spearman Rank Correlation Test). The most negative values are found in the saltbush community that exhibited the high EC readings.

Table 2.--Correlations of mean predawn water potentials of Atriplex canescens by study site and area using Spearmans' Rank Correlation; test for significance by Duncan's Multiple Range Test.

Area	Study site	Aug. 1982-Mar. 1983	Apr. 1983 Aug. 1983
Natural	Saltbush	[1]32.6 a	[2]20.0 b
	Rabbitbrush	29.3 a	19.1 b
Reclaimed	Extra topsoil	20.0 b	17.6 b
	Pre-Law	15.1 b	15.2 b
	Post-Law	15.0 b	13.1 b
	Natural	30.9 x	19.6 y
	Reclaimed	16.7 y	15.3 y
	($p < 0.01$, $F = 13.62$, $n = 345$)		

[1]All means given in -bars; 1 bar = 0.10 MPa.

[2]Means followed by the same letter are not significantly different at 0.01 probability level.

Seasonally averaged plant water potential readings measured at the natural areas were significantly more negative ($p<0.01$) than at the reclaimed areas, especially during the period of August 1982 through March 1983. This indicates that less soil moisture was available to plants growing on the natural sites through most of the year, thus increasing the level of plant moisture stress. No significant difference is seen between natural and reclaimed sites for the drier period of April-August 1983.

Monthly minimum and maximum stress values of plants growing on the extra-topsoil site and in the saltbush community are compared in table 3. Values are significantly different between sites at each date. Both minimum and maximum measurements demonstrate significantly higher water stress for plants growing on the natural site from August 1982 until May 1983 (table 3). During the critical

Table 3.--Comparison of seasonal predawn minimum and midday maximum water potential values[1] for Atriplex canescens at one natural and one reclaimed site using Duncan's Multiple Range Test. All means followed by the same letter are not significantly different (p<.01).

Time of day	Date	Saltbush community	Extra topsoil
Predawn maxima	8/21/82	[2]26.0 a	18.4 b f
	1/07/83	30.8 c	27.3 a
	5/30/83	7.1 d	12.5 e
	6/18/83	13.5 e	17.1 b
	7/04/83	26.0 a	19.2 b f
	8/27/83	34.0 c j	21.5 f
Midday minima	1/07/83	46.4 g	33.7 c j
	5/30/83	26.1 a	31.7 c
	7/04/83	46.4 g	39.5 h
	8/27/83	50.4 i	35.7 j

[1]Each value represents mean of 8-11 observations.

[2]All means given in -bars; 1 bar = 0.1 MPa.

period from April through June, the soil on the reclaimed site dried out more quickly, causing plants to exhibit more water stress than those of the undisturbed site. This reversal is shown graphically in figure 1, which compares a natural and reclaimed site in May and July. These data appear to contradict the data for the same period in table 2. However, by seasonally averaging the predawn water potential over the entire period (April-August), it only appears that there was always less moisture available in the undisturbed area. When a monthly check of water potential values is examined (table 3), it is apparent that the actual trend is hidden. This trend is demonstrated

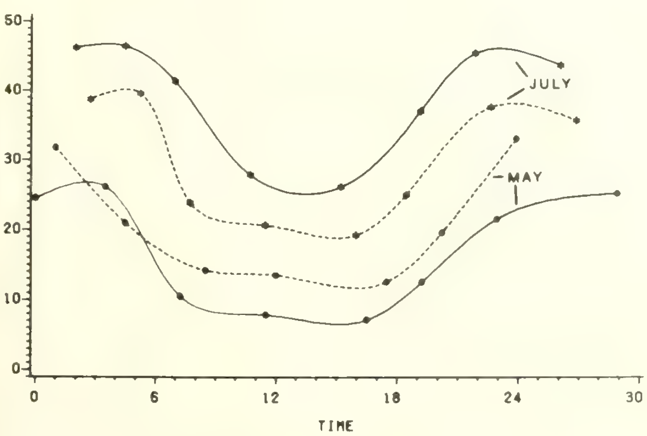

Figure 1.--Comparison of diurnal pattern of plant water potentials at natural and reclaimed sites in May and July 1983. ——— = natural site; -------- = reclaimed site. 1 bar = 0.1 MPa.

by the decrease (becoming more negative) in both the predawn maxima and the midday minima values measured at the reclaimed site. During summer drought, the relationship between the vegetation and the moisture gradient can best be shown by comparing the minimum (most negative) internal water stress at midday rather than the maximum (predawn) (Waring and Cleary 1967; Halvorson and Patten 1974; Syvertsen and others 1975).

The mean difference between daily minima and maxima water potential values for all seasons was 23.5-bars for the natural site and 17.6-bars for the reclaimed site. This difference dropped to 18.8-bars and 19.7-bars respectively during spring and early summer 1983. Although the differences were no longer significant, there was a reversal of pattern. The reclaimed site showed a slightly greater difference between the diurnal maxima and minima. Halvorson and Patten (1974) found that diurnal water potential fluctuation increased with decreasing soil moisture availability. The greatest fluctuation on both sites occurred during periods of the greatest moisture stress, either during the driest period or during the cold winter when water availability was limited by low temperatures.

The seasonal range of maximum and minimum water potential values varied from -6.4-bars to -67.2-bars at the natural site and from -12.5-bars to -39.5-bars at the disturbed site. However, both extremes at the natural site were influenced by climatic anomalies: the -6.4-bar maximum was measured during a September rainfall, and the -67.2-bar minimum during 5° F (-15° C) temperatures in early spring. Removing these two anomalous situations from consideration, the range on the natural site was -7.1-bars to -50.4-bars (table 3). As the summer monsoon season commenced in July, but with below normal precipitation, the reclaimed soils absorbed more moisture and once again the natural soils showed the greatest moisture stress. This pattern may have been influenced by the above normal precipitation during the winter and spring of 1982-83, and the light summer monsoon rainfall of 1983.

Mean predawn water potentials during August 1982 for shrubs in the rabbitbrush community were: A. canescens, -29.3-bars; Artemisia tridentata, -33.5-bars; Chrysothamnus viscidiflorus (Hook.) Nutt., -31.3-bars. Although not significantly different, the A. canescens plants showed slightly higher (less negative) water potential values than the other neighboring shrubs. By comparison, midday values for shrubs growing on the rabbitbrush site in July 1983 were: A. canescens, -39.6-bars; A. confertifolia, -46.1-bars; and Eurotia lanata (Pursh.) Moq., -46.4-bars. The saltbush plants did have significantly higher (p<0.01) water potential

values during this summer drought season, indicating that they were operating under less moisture stress than the other shrubs.

Diurnal patterns of plant moisture stress are compared with the vapor-pressure deficit of the atmosphere (VPD) for A. canescens in the saltbush community in figure 2. During September 1982 there was high soil moisture content, low vapor-pressure deficit, and low plant moisture stress due to heavy seasonal precipitation. Significant correlation was

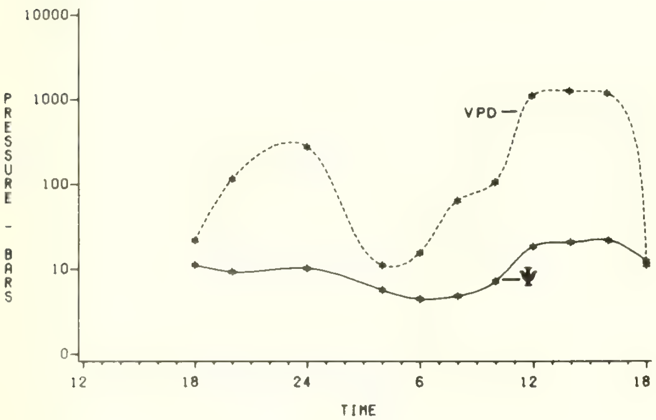

Figure 2.--Comparison of diurnal pattern of moisture stress and atmospheric vapor-pressure deficit for Atriplex canescens at saltbush community on Sept. 4, 1983. 1 bar = 0.1 MPa; VPD = vapor-pressure deficit; Ψ = plant water potential.

found between plant moisture stress and VPD ($F = 63.0$, $r^2 = .87$; Pearson product-moment correlation). Water potential measurements did not increase markedly until 1100 hours when the skies cleared and the vapor-pressure deficit began to rise. In January, cold nocturnal temperatures (<14° F; <-10° C) further depressed the VPD, which rose only during the warm midday hours (1300-1800 hours). Cold temperatures also depressed the typical peak of increasingly more negative plant water potential values that occurs immediately after sunrise with the rapid increase of the VPD and stomatal opening (Klepper 1968).

Plant water potentials were not significantly correlated with VPD during the cold winter months. This was primarily due to low soil water availability caused by extremely low soil temperatures. The high day time temperature difference between the air and soil caused the plants to experience extreme moisture stress. At all other times of the year, plant water potentials and VPD were highly correlated ($r^2 = .70$ to $r^2 = .96$). In all cases, plants under the least moisture stress showed the highest correlation between water potential and VPD.

An anomalous diurnal plant water stress pattern was detected during the cold winter months when the air temperature routinely dropped below 19° to 14° F (-7° to -10° C) and soil temperatures at 2- and 8-inches (5- and 20-cm) dropped below 23° and 32° F (-5° and 0° C) respectively. Unable to efficiently recharge from the soil moisture at night due to the low temperatures, the plant's period of minimum stress came in the early evening immediately following sunset (1800-2000 hours). December 1982 predawn readings went beyond -70-bars (off scale) at both natural sites when the temperature dropped below 5° F (-15° C) (returning to mean maximum -40.7-bars at 1200 hours). This pattern remained constant until March when nocturnal temperatures began to rise above 32° F (0° C). Other anomalous patterns have been reported (Syvertsen and others 1975) due to effects of soil moisture or stomatal closure. Note the rapid rise and immediate decline of the water potential curve at sunrise during March in figure 3 due to the early attainment of stress conditions and possibly subsequent stomatal closure (Cline and Campbell 1978). The stress was intensified by the extremely cold predawn soil and atmospheric temperatures (21° F; -6° C) that prevented easy water movement through the soil-plant-atmosphere continuum.

Water potential measurements from September, January, March, and July are overlaid in figure 3 to display the gradual increase in plant water stress from September 1982 through July 1983. Of particular interest is the close agreement of the afternoon (1200-1800 hours) water potential values at all dates, which contrasts with the widely

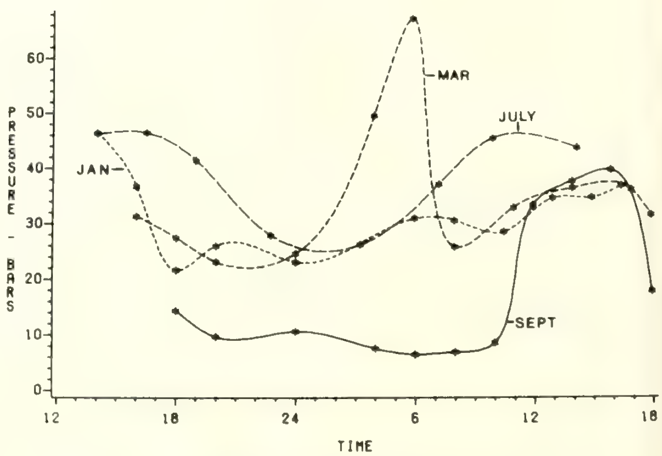

Figure 3.--Seasonal comparison of four moisture stress patterns of Atriplex canescens at saltbush community for September 1982, and January, March, and July 1983. 1 bar = MPa.

disparate values during the remainder of the diurnal cycle. The March peak (most negative potential) appears anomalous in comparison with the other moisture stress patterns and may be due to high water stress during the day and the inability of the plant to recharge sufficiently at night due to low nocturnal atmospheric and soil temperatures that prevent efficient water uptake by the roots.

A high degree of variability in water potential measurements was detected among A. canescens sampled on all sites at all seasons. Differences were not significant between sites, but there was a trend toward greater variability with greater moisture stress or during periods of climatic fluctuation (e.g., precipitation). No significant difference was detected between sites, or between natural and reclaimed areas. Mean variability measured 7-bars, with occasional values to 15-bars.

Stutz (1982) has reported that Atriplex is by far the most variable of all western America chenopods, commonly forming numerous locally adapted ecotypes through rapid gene mutation and introgressive hybridization. The genetically controlled adaptations include variations in root-sprouting capability, tolerance of heavy clay soils, and drought tolerance. It is suggested that much of the plant water potential variability between A. canescens individuals of the same ecotype or site can be explained by this genetic diversity.

Pressure-Volume Curves

Scholander and others (1965) stated that "the pressure-volume curve gives a striking picture of the water stress of a plant and reflects with fair accuracy the turgor of the leaf cells," by delineating a plant's water potential components. A plant's adaptation to drought stress is reflected in its low seasonal water potential components (Monson and Smith 1982). Species in habitats characterized by periods of substantial water stress exhibit relatively low (more negative) internal osmotic potentials with positive turgor pressure. Total plant water potential = osmotic potential + turgor pressure (Cline and Campbell 1976; Roberts and others 1980). The capacity to maintain turgor at low water potentials allows a plant access to both a greater volume of soil water and a longer growing season, and to be physiologically active during periods of low soil water and high atmospheric demand (Monson and Smith 1982).

Pressure-volume curves shown in figure 4 allow a comparison of three shrubs from the rabbitbrush community on August 22, 1982. The data in table 4 compare the osmotic potential at full turgor and the turgor loss potential values obtained from these curves. The osmotic potential at full turgor (or initial osmotic potential) is obtained by calculating the intercept of the linear portion of the pressure-volume curve at 100 percent RWC (relative water content) by least squares regression (Jane and Green 1983). It has been stated that variation in the water potential at the turgor loss point is closely correlated with osmotic potential and could be used to rank species in order of increasing drought adaptability and stress

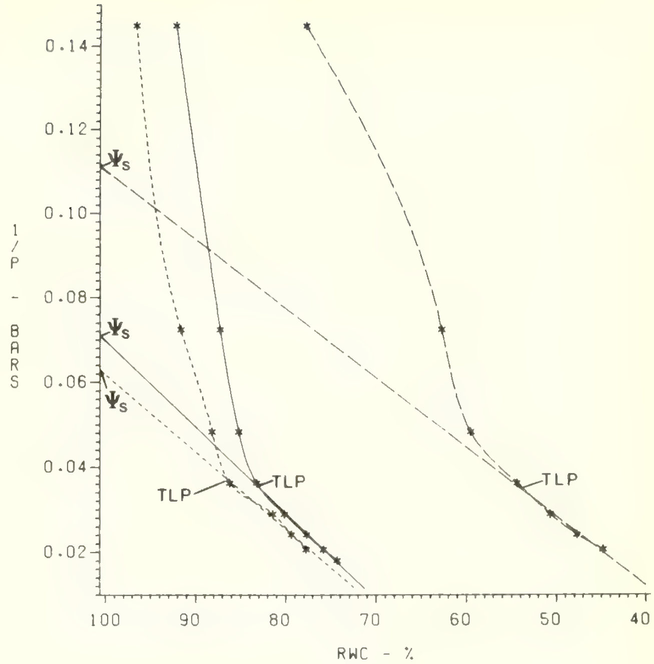

Figure 4.--Pressure-volume curves for three shrub species at rabbitbrush community on Aug. 22, 1982; each curve is the mean of four observations. ——— = Atriplex confertifolia; -------- = Atriplex canescens; — — — = Artemisia tridentata; linear regression line by least squares method. TLP = turgor loss point; Ψ_s = initial osmotic potential at full turgor.

Table 4.--Water potential components obtained from pressure--volume curves for shrub species in the rabbitbrush community. All values are in -bars; each value is the mean of 4 values.

Species	Date	Osmotic potential (full turgor)	Turgor loss pot.
Atriplex canescens		20.7	31.9
Artemisia tridentata	4/14/83	15.2	27.6
Chrysothamnus viscidiflorus		19.8	28.4
Atriplex canescens		16.2	31.9
Artemisia tridentata	8/22/82	9.1	24.9
Atriplex confertifolia		14.3	33.0

toleration (Monson and Smith 1982; Jane and Green 1983). Additionally, Hinckley and others (1980) found a close link between the turgor loss point and the turgor potential threshold for stomatal closure.

As seen in table 4, A. canescens had significantly more negative values than Artemisia tridentata on both dates. No significant difference was seen between A. canescens and either Chrysothamnus viscidiflorus or A. confertifolia. Comparison of the shapes of the curves of figure 4 can also be made. A. canescens showed the least decrease in RWC for a given decline in water potential, indicating a greater drought resistance (lower line, steeper angle and slope) (Hinckley and others 1980; Clayton-Greene 1983). Using the osmotic potentials and shape of the curves, the rank of the shrubs in order of decreasing drought resistance potential was: Atriplex confertifolia > Chrysothamnus viscidiflorus > Atriplex canescens > Artemisia tridentata.

The ability of a plant to control or influence its seasonal internal osmotic potential (osmoregulation) is expressed in its total osmotic variation (Monson and Smith 1982; Jane and Green 1983). Increasingly negative osmotic potentials are an adaptive response to lowered soil moisture availability. The lower osmotic potential steepens the water potential gradient from substrate to plant, allowing turgor to be maintained at lower plant water potentials (Roberts and others 1980). Comparison of osmotic measurements of A. canescens from both tables 4 and 5 shows no significant variation in osmotic potential, indicting no great capacity for osmoregulation. In contrast, Artemisia tridentata showed great osmotic variablity between the two dates, indicating that it is an osmoregulator.

Table 5.--Comparison of water potential components for Atriplex canescens from various sites on two dates. All values are in -bars; each value is mean of 4 observations.

Site	Date	Osmotic potential (full turgor)	Turgor loss pot.
Rabbitbrush		13.6	31.3
Saltbush	6/18/83	19.9	33.1
Extra topsoil		16.2	31.4
Saltbush		19.7	38.6
Extra topsoil	7/04/83	17.7	27.9
Pre-Law		17.9	30.0

However, there was a decrease in the turgor loss point (table 5) in A. canescens sampled on June 18 and July 4, 1983, associated with a decrease in soil moisture availability (-33.1- to -38.6-bars). This would allow the plants in the saltbush community to maintain turgor while the soil moisture decreased, and indicates at least some capacity for osmoregulation, despite the slight variation in osmotic potentials.

Comparison of the pressure-volume curves for A. canescens grown on different sites (table 5 and figure 5-6) reveals that plants from the saltbush community had significantly more negative initial osmotic potentials, turgor loss potentials, and steeper slopes to their respective curves than plants from the rabbitbrush community, or from either reclaimed site. This indicates that A. canescens plants growing on natural sites have greater drought-resistance potential then those on reclaimed sites. The significant difference between sites is indicated in the slope of the curves shown in figure 5.

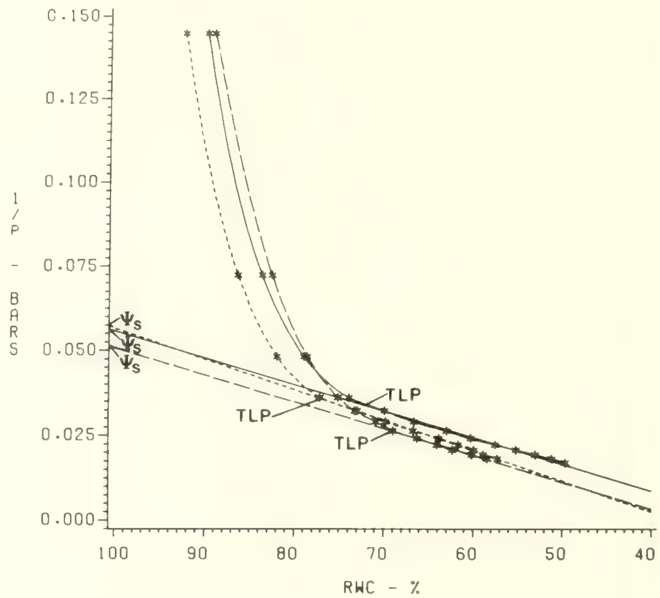

Figure 5.--Pressure-volume curves for Atriplex canescens at three sites on June 18, 1983; each curve is mean of four observations. ——— = rabbitbrush comm.; ------- = extra topsoil; – – – – = saltbush comm.; linear regression line by least squares method. TLP = turgor loss point; Ψ_s = initial osmotic potential at full turgor.

CONCLUSIONS

Reclaimed sites on Black Mesa contained more soil water than natural sites from August 1982 to March 1983. But during the period of most extreme moisture stress, April to June 1983, the pattern reversed; the natural soils contained more water. The lack of water in reclaimed soils during this critical season, coupled with high clay content and significantly higher salinity values, produced very negative soil water potentials;

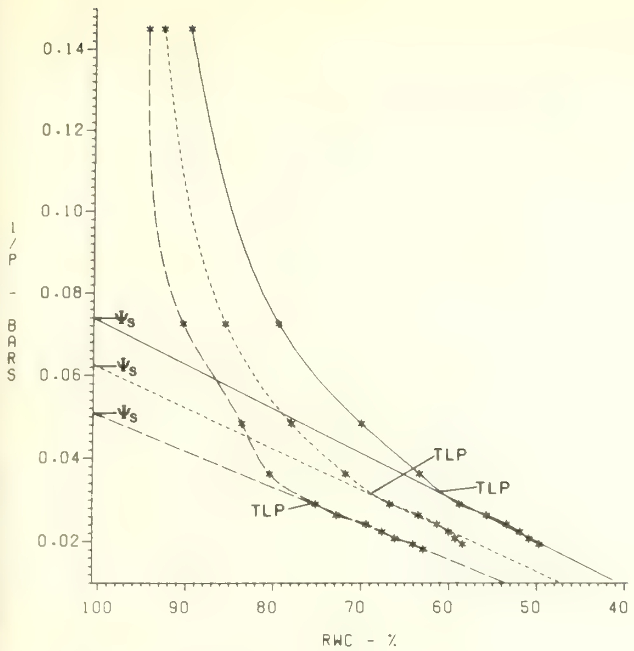

Figure 6.--Pressure-volume curves for Atriplex canescens at three sites on July 4, 1983; each curve is mean of four observations. ——— = post-Law; ------- = extra topsoil; — — — = saltbush comm.; linear regression line by least squares method. TLP = turgor loss point; Ψ_s = initial osmotic potential at full turgor.

these may have adversely affected plant establishment and mortality. Atiplex canescens appears capable of tolerating high moisture stress through ecotypic adaptation, genetic variability, and physiological drought-resistance capability.

Pressure-volume curves indicate that A. canescens plants from natural sites have lower initial osmotic potentials and maintain positive turgor at lower water potentials than plants from disturbed sites, giving them a greater drought-resistance potential. Pressure-volume curves indicated that A. confertifolia has a greater dought tolerance than Chrysothamnus viscidiflorus, Atriplex canescens or Artemisia tridentata growing on the same site.

The ability of A. canescens to osmoregulate as a means of dealing with increasing moisture stress needs further investigation. More study is also needed on comparing the moisture stress patterns of important members of all major plant communities in the area and determination of their internal water potential components.

The necessity of using native shrubs that can withstand intensive grazing pressures and dessicating conditions for ecosystem stabilization is well documented (Packer 1974; Aldon 1978). Atriplex canescens is one of the most important shrubs for revegetation in the arid Southwest (Plummer 1977), especially in reclaiming mine spoils that have been physically and chemically altered. Internal water potential components may be used to compare drought-resistance capacities of various species, or their degree of moisture stress in various microhabitats. Although A. canescens is well-suited for revegetation activities, its great physiological and morphological variability makes it unacceptable as a reference plant (Klepper 1968; Waring and Cleary 1967; Stutz 1982) to detect differences in soil moisture regimes.

Plant-soil-atmosphere water relations are the key to successful colonization of harsh arid sites. Additional research is being completed to correlate the soil water potential with the total plant water potential and atmospheric vapor pressure deficit on natural and reclaimed sites. This will allow correlation with the actual plant water potential variations taking place. More study on individual plant water potential components and requirements is also indicated to determine the best procedures to follow when revegetating disturbed lands in the arid Southwest.

ACKNOWLEDGEMENTS

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THE GREAT BASIN COLD DESERT: SOME PHYSICAL GEOGRAPHY

Ralph C. Holmgren

ABSTRACT: This paper is a revised version of an invited, informal chat presented at the Wendover, Nevada, overnight stop of the symposium tour. An overview of the geological history, physiography, climate, and hydrology of the eastern Great Basin is presented and used as background in a discussion of the nomenclature of the major regional desert plant associations.

INTRODUCTION

Today, on the first leg of our field tour, we saw in their natural elements some of the chenopodiaceous species whose biology will be discussed in papers later this week. What I propose to talk about tonight is not so much the biology as the elements--earth, water, and air--in which the biology takes place. Let's call this an informal geographical review of the country we traversed today and will see more of tomorrow: the Great Basin cold desert.

The woody-perennial component of family Chenopodiaceae in North America is almost synonymous with this Temperate Zone desert. Chenopodiaceous shrubs are among the dominant species in nearly all of its plant communities. My own desert experience has been a parochial one, so what I have to offer about the physical geography--the abiotic environment--of deserts and how it relates to community distribution applies most particularly to the kind of desert we saw today; that of the northeastern part of the Great Basin.

The variation we see on the desert as expressed by its plant cover derives from the varying influence of four fundamental and, to some degree, interrelated abiotic factors: physiography, geological history, climate, and hydrology. The last two, climate and hydrology, might be considered partial functions of the other two, geology and physiography. A fifth attribute, one of special interest to chenopodiologists, is the distribution of soluble soil salts. It depends directly or indirectly on the other four.

Our cold-desert vegetation has been described and classified by a number of observers over the past century. One very good classification scheme, that of H. L. Shantz of about 60 years ago, seems to have been the most popular and the most durable. But it only seems that way. In reality, it has endured only in some of its nomenclature, nomenclature for the most part long misapplied. It is with regard to the neglect of the descriptive definitions which Shantz provided along with his names for desert plant formations and associations that I want to bring geology and hydrology into the picture. Let us look at these two aspects of the Great Basin desert and rediscover by that physical route what Shantz observed by looking at plant communities: that this land of chenopod dominants is in fact two deserts, one climatic, the other hydrologic, the latter possibly not a desert at all.

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GEOLOGY AND PHYSIOGRAPHY

For a very long time, perhaps as long as 600 million years, the crust of the earth in what is now northwestern Utah and northeastern Nevada was comparatively stable. For most of that period it was a marine environment--not an oceanic depth, but shallow-marine. While sediments of muds, limes, and dolomitic materials, and sometimes shoreline sands accumulated to great thicknesses, the shallow sea condition was maintained (with some intervals when the area was above water) presumably by slow crustal subsidence under the gathering weight. The hard rocks we see exposed in our present-day mountains are these ancient (Paleozoic and older) sediments. The exposed strata are in many places much contorted and broken, evidence of a later period of diastrophism that began less than 200 million years ago: uplift and horizontal compression, metamorphism at great depths, folding, faulting, and thrusting. But this great mountain system is not the mountains we see today. Over long ages, the mountains built from materials of the once stable, nearly horizontal, shallow seabed (or sometime lowland) largely eroded away.

Then, much later, beginning about 25 million years ago, in another period of crustal upwarping, less violent and less complicated than the previous one, a broad bulge almost a thousand miles across came into being. It still exists as the highlands known today as the Mountain West. During the early history of this uplift, in places not far from here (Wendover), mostly to the south and west, molten rock rose from great depths through the jumbled sedimentary strata of the roots of the former mountains to erupt and spew volcanic material over the eroded land surface.
Rather late in the history of the regional bulge, its western part, roughly the present area of

Nevada and western Utah, began to take on the shapes of our present landform. For the past few million years, and continuing even now, vertical slippage of the crust along many almost parallel north-south trending faults, with uplift on one side and downdrop on the other (block faulting), has given us the basin-and-range physiography that characterizes the Great Basin today: a system of long and rather narrow north-south trending mountain ranges separating valleys of similar dimension and orientation. As the mountains have risen, they have also been eroding, and the intervening valleys have filled or partially filled with the outwash material--unconsolidated conglomerate, rubble, sorted and unsorted alluvium of particles ranging in size from boulders down to clays, all derived from the ancient marine strata or, in some valleys, with admixture of volcanics. This fill material, resting on underlying bedrock, may be hundreds of feet thick beneath the present valley floors.

The valleys also collected water. Lakes have undoubtedly come and gone in most of them while the geological structure, the physiography, and the climate have been changing. Evidence of all but the most recent of the lakes is now obscure, having been buried under subsequent valley fill or erased from hillsides where former shorelines stood.

Typically, the valleys today have a wide fringing area of alluvial slopes (fans, bajadas) near the bases of their bordering mountains. The soils high on these slopes, nearer their mountain source, are stoney-gravelly. Valleyward, the material tends to be less and less gravelly: loamy sands, sandy loams, and loams. The central floor of the wider valleys is nearly flat, and in valleys which contained lakes late in the Pleistocene Epoch, the soils may be rather high in clay content. Clayey layers in the material far below the present floor provide evidence of earlier lakes at times when the valley fill was not as deep as it is now.

Some of the Great Basin valleys have no topographic exits for surface water drainage. Thus any waters that flow, as from high-intensity rainstorms or, rarely, from extremely rapid snowmelt, or permanent or seasonal small streams, can go only as far as the lowest part of a valley, where there may be a lake or, more commonly, the bed of an ephemeral lake--a playa--a flat surface of heavy soil bare of vascular plants. Other valleys may have surface water drainage into a lower, neighboring valley. These valleys have structural breaks in their mountain border, or the fill has accumulated to such a level as to bring the floor to the elevation of a pass for outflow. But in our present arid climate no water flows from any of these valleys all the way to the sea. This is a land of interior drainage, a land of many independent one-valley (or few-valley) drainage systems which all together were first called the Great Basin by Captain J. C. Fremont nearly 140 years ago. The only escape for water is by evaporation.

Near the end of the Pleistocene, there were at least a hundred large lakes in the Great Basin valleys. Some were quite deep; some stood at levels high enough for water to spill over mountain passes into other valleys, gaps now high and dry. Most of today's trip was across the bed of former bays and the main body of the largest of the late Pleistocene Great Basin lakes, Lake Bonneville. It was still in existence as recently as 10,000 years ago. Its former shorelines, sculptured by wave action and shore currents while the water surface stood for considerable lengths of time at certain elevations, are readily visible yet as benches, terraces, and seacliffs on the slopes of mountains. Some of these features are hundreds of feet above the present valley floor.

When there was a lake in a valley, the unconsolidated mineral material of the underlying fill would, of course, contain water in the interspaces. And when, in the drier climate of more recent times, the evaporation rate exceeded the rate of water replacement from the atmosphere and the lake finally disappeared, there still remained a substantial subterranean reservoir. Water still continues to move into this reservoir, and excess water from underground storage is still cycling back into the atmosphere. Of course, the rate of turnover is less now, but in a desert valley of average size it is estimated to be a few tens of thousands of acre-feet of water per year.

PRECIPITATION AND SOIL MOISTURE

We are a long way from the ocean and in the rain shadow of distant broad and high mountain ranges which capture most of the moisture from maritime air masses that move this way. In addition, each valley is in the rain shadow of the mountain immediately to its west, the direction from which most of our winter moisture arrives. Hence the desert in the valleys. Fall-to-spring precipitation may be four or more times as much in the mountains as in adjacent valleys. It comes mainly as snow, accumulating over a period of several months, to become available to plants during one short period in the spring when temperatures first become favorable for plant growth. At that season, consistently and reliably, year after year, the soil moisture supply is there and at its highest. The depth of wetting is then also the greatest. Where mountain soils are deeper or thicker over bedrock, there will be more moisture stored, lasting for a longer period of use, and plant cover will be lush. But where the soils are shallow, there is a surplus of water beyond that which can be retained. In some topographic situations, such as those favoring accumulation of wind-driven snow, there can be water in excess of what even the deeper soils can retain. The excess water drains away over or through the underlying bedrock, some of it not to be seen again as it finds its way to a reservoir under a valley, some of it to reappear as spring freshets, intermittent brooks or (in the larger, higher mountains) permanent streams in the canyons. When the water of the little mountain creeks reaches the canyon mouths it does not go very far out onto the alluvial fans before it,

too, disappears, seeping down through the gravels of the streambeds to become part of the groundwater.

Winter moisture in the mountains, then, is the major source of water under the arid valleys. Another upland source is summer storms of such high intensity that much of their rainfall runs overland to gather as torrents in the canyon streambeds and escape sometimes far out onto the fans, but yet mostly sinking into the gravels. Only occasionally do some small amounts flow well out across the valley floor. Just as there are mountains (humid islands, as someone has called them) scattered across the Great Basin, so are there many water-containing catchments under the desert valleys.

As I have already mentioned, the valleys receive only a fraction as much cool- and cold-season precipitation as the mountains. They are winter arid. But, as in the mountains, winter moisture is stored moisture, and when it becomes warm enough in the spring for plants to grow on the desert, there is bound to be water sufficient for some growth. Depending on the amount of precipitation that comes over the winter months, the depth to which the soil is wetted and the amount of water that is stored will vary greatly from year to year. But whatever the amount, it is almost always within reach of roots; a surplus for deeper drainage would be unusual.

There may be moisture enough in spring for growth for a few weeks, or for several, but for summer growth there has to be warm-season precipitation, which on this desert may arrive in effective amounts at times not so predictable as the early spring moisture. Summer rains are unpredictable both as to timing and location, but generally we can expect to have at least one, and usually two or three, periods of monsoonlike storms during the warm months.

With summer storms, there is not the disparity between amounts of water falling on mountains and valleys that we have noted for the winter season. Winter precipitation is distributed orographically, because the air masses at that time move mostly from the west, a direction normal to the axes of the mountains, and lose moisture as they rise to pass over them. Summer storms are convectional from moist air masses which most often move more nearly northward in a direction generally parallel to the mountains. Thus, summer showers, of varying intensity and duration, are almost as likely to occur in the valleys as in the mountains. Both the mountains and the valleys can be considered arid in the warmer months: dry with infrequent, unpredictable, scattered rain. The valleys are more desertic than the mountains because of higher daytime temperatures and greater evaporation stress, as well as the fact that they receive less rain and snow, autumn to spring.

The plant species of the arid valleys are comparatively few. Individual small shrubs and grass plants are widely dispersed, and much ground is exposed. Plant cover is low, ranging from 5 to 15 percent. This kind of desert, living on the rain that falls on it, is one of the two that Shantz pointed out. He labeled it the Northern Desert Shrub Formation and named seven of its "associations," four of which he described as dominated by woody chenopods. We should now go back and consider further the groundwater movements, the Great Basin hydrology, to see a much different situation where we find the second cold desert of Shantz--the one he called the Salt Desert Shrub Formation. Five associations were named and briefly described in the paper where the formation was named; all of them have chenopod shrub dominants.

HYDROLOGY

We have already considered two kinds of topographic valleys: those that are closed, having lakes or playas as the ultimate destination of flowing waters; and those that are open, with drainage into a neighboring valley. Hydrologically, also, as C. T. Snyder has pointed out, there are two general kinds of valleys: those without an underground outlet (the valley fill and its water being contained in a sealed bedrock bowl) and thus having a regional water table very near to or at the ground surface in the lowest parts of the valley; and those where groundwater can escape through subterranean outlets (leaky bowls) and having a water table at depths too great for water loss by evaporation to be significant and usually too deep to be reached by roots. Combining topographic and hydrologic conditions of drainage, we now recognize four general kinds of valleys. Two of them, those with underground drainage, where the regional groundwater surface may be hundreds of feet below the ground surface, have, except in occasional small areas, only the plant associations of the Northern Desert Shrub. The exceptional areas, where species more typical of the Salt Desert Shrub may be found, are areas receiving surface inflow from heavy rains elsewhere, not necessarily every year; and places where local, small, nonregional water tables perched on some underground clayey stratum (possibly related to a lake bed older than late Pleistocene) are near to or intercepted by a sloping ground surface: seepy sites. In these irrigated or subirrigated spots there will be such species as greasewood (Sarcobatus), seepweed (Suaeda), saltgrass (Distichlis), and one or two phreatophytic taxa of rubber rabbitbrush (Chrysothamnus nauseosus).

In the other two kinds of valleys, the ones where groundwater does not leak out, much of the area (lower hills, alluvial slopes, benchlands, and some valley floor) is also Northern Desert Shrub--the climatic desert. It is only on flat lowlands where we find the phreatophyte communities of the Salt Desert Shrub as Shantz described it. The Salt Desert Shrub probably occupies less than half the area of the valleys in which it is important, but in the whole of the Great Basin, its total acreage is substantial. We saw this desert today in the neighborhood of Grantsville, and again on either edge of the barren Great Salt Lake Desert.

Visualize a valley with wide fringing alluvial slopes and a less steeply sloping, almost level valley floor. Visualize also an underground water surface even more nearly level, with whatever slope it may have being toward the very lowest part of the valley. If the valley is drained topographically, this lowest part may be toward one end or near a side of the valley. If the valley has no outlet, the low area will be more centrally located and will be occupied by a playa, white with salt when its surface is dry. The two surfaces, valley bottom and water table, because of their differing slopes are far apart in the area of the bajada and the higher parts of the flatter valley floor. The vadose water is beyond the reach of the most deeply rooted plants, and the desert is climatic. But there is a line, often well-marked by an abrupt vegetation change, that defines the limits of the area in which the water table is within reach of roots. This is where the hydrologic desert starts, and all the associations listed for it by Shantz have as their dominants halophytic phreatophytes.

As the groundwater slowly moves under this desert, its upper layers become more saline the farther it progresses. First the deeper rooted, and then farther on the less deeply rooted, species extract water, leaving a higher concentration of salts as the water table comes into proximity with the ground surface. Commonly, a system of plant communities arranged more or less concentrically around the salty playa is the result. The more deeply rooted and less salt-tolerant species found in the outer bands drop out and other species with greater salt tolerance appear as the distance to the salty playa (or the topographic valley outlet channel) becomes less. Finally there are only pickleweed (Allenrolfia) and samphire (Salicornia), as we saw today, scattered widely at the edge of the playa. The playa itself is an evaporating surface. There are seasonal fluctuations in the level of the water table, and there are infrequent times of higher than average precipitation when the water table is at a higher elevation than the lake bed. At such times, the playa is a lake. Most of the time, however, the playa is simply a flat area of salt crust over heavy, almost always muddy, soil material from which water continues to evaporate and on which salt crystals continue to grow.

SHANTZ'S TWO COLD DESERTS

Now we can take a look at the two deserts Shantz saw and talk about the mischief that has been made of a fine old work of phytosociologic taxonomy. Shantz listed his cold-desert plant communities (he called them associations) approximately in the order of increasing alkali tolerance and, for part of the way through the list, of increasing drought tolerance of the species. But at a point after the seventh of his twelve associations, the order is that of increasing moisture availability and increasing salinity of that moisture.

All of these phreatophyte communities in the Salt Desert Shrub Formation were named for their dominant chenopodiaceous shrubs. But four of the seven associations of the Northern Desert Shrub, his desert that does not rely on supplemental water, are named for chenopods, too. Succeeding ecologists have reasonably recognized several important differences between the sagebrush (Artemisia) associations of Shantz--the associations of the least arid part of his climatic desert--and his other Northern Desert Shrub associations. When these ecologists began to speak of a sagebrush desert zone as a separate entity, this left five Northern Desert Shrub associations to fall by default into the salt desert, apparently because of their chenopodiaceous names. What we have called the Salt Desert Shrub for many years now is no longer the well-defined taxon it once was. An important and readily apparent boundary on the ground was erased in the language.

The logic, I think, goes something like this. The dominant species are chenopods. Chenopods are halophytes. The chenopod-dominated communities, then, are edaphic; salinity modifies the climatic expression of the vegetation. But other workers, notably W. D. Billings, have shown that for some of the so-called halophytes, the presence of salt is not required. Billings also showed that in nonirrigated places where the climate is too arid for sagebrush to grow, chenopods can and do. He suggested that dryland chenopod communities be considered a climatic vegetation zone different from both the less arid sagebrush and what he considered the edaphically controlled salt desert (Shantz's original Salt Desert Shrub). He called his climatic desert the Shadscale Zone. This was a desirable step away from what had become confusion in our communications about cold deserts, but ecologists seem content not to follow. The Billings terminology is little used.

About 15 years ago, F. A. Branson and his coworkers proposed that the communities of watered lowlands not be called desert at all, but salt marsh. This name, slow to catch on, is desirable in that it allow us to toss out the old label "Salt Desert Shrub," which has had an unfortunate history, and use the term salt marsh for the phreatophyte communities found in so many of our climatically arid valleys. Sad to say, however, the Branson group wants to keep the term Salt Desert Shrub, applying it to the original Northern Desert Shrub associations exclusive of the sagebrush--the Shadscale Zone of Billings.

I hope that, as time goes on, we can forego altogether the use of "Salt Desert Shrub" in our discussions, possibly following Billings for a name (Shadscale Zone) for our climatic desert, and Branson (Salt Marsh) for the hydrologic desert, yet somehow not forgetting Shantz, who pointed out the distinction long ago.

Three things we should remember about the Salt Desert Shrub are: First, when we see or hear the term, we should look for or ask to have a descriptive definition of what is implied. Second, the old salt desert, now perhaps salt marsh, is not a desert in a climatic sense and can be found in climates where no neighboring communities are desertic. Third, in the Great

Basin, it usually is marked on its outer edge by the presence of greasewood and extends downward elevationally from there. As you travel in a number of valleys, you will notice that it is a distinct formation clearly defined by color and physiognomy. If there is a playa in its midst, its dry surface will be white rather than the light buff color of desert soil. And if you are traveling longitudinally in a valley having this "marsh desert", it will be the vegetation you see on the lower side of the road.

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Hydrology

[Note: Numerous investigations of the groundwater resource in the Great Basin valleys have been made in the past 70 years. Contained in the hydrologic literature is a mine of information on native plant distribution as related to plant-root proximity to (and salinity of) imported water which few ecologists and plant geographers seem to be aware of. Meinzer, in 1917, said "Groundwater discharge is shown with considerable fidelity by plants of certain species that are found almost exclusively in shallow-water districts." He said our vegetation can be put into three "groups"--we can call them formations or zones--and he listed a zonation of dominant plant species in much the order that ecologists have done. Meinzer added that water discharge areas could be mapped "with nearly as much precision as rock outcrops" by using these vegetation indicators; and many subsequent reports do indeed have such detailed maps.

In the early years, groundwater investigation was largely the province of the U.S. Geological Survey, but there are also now available many reports issued by State resource departments, water departments, and engineers' offices for Nevada, Utah, and California. I list below only a few, some of several which in my estimation are valuable contributions to a better understanding of Great Basin plant ecology.]

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Section 3. Physiology

CHANGES IN FREE AMINO ACIDS AND GUANOSINE NUCLEOTIDES IN

ATRIPLEX CANESCENS (PURSH)[NUTT.]DURING WATER STRESS

William A. Cress

ABSTRACT: Water stress of Atriplex canescens seedlings resulted in changes in levels of several nonbound amino acids. Glutamate decreased from 12 µmol. per gram fresh weight to an undetectable level. Asparagine increased from 16 to 30 µmol. per gram fresh weight. An overall decrease in guanosine nucleotides of 32 percent was noted. The decrease in glutamate and in guanosine nucleotide contents along with an increase in asparagine content during water stress suggest a cause-effect relationship between the decrease in glutamate and the decrease in polysomes during water stress.

INTRODUCTION

A number of metabolic changes occur when plants are subjected to water stress. These include: an increase in total free amino and imino acids (Barnett and Naylor 1966), an increase in amides (Barnett and Naylor 1966; Thompson and others 1966), an increase in quarternary amines such as the betaines (Hanson and others 1978), and an increase in abscisic acid (Milborrow 1974). There has been much speculation as to whether the production of stress metabolites, compounds which increase in concentration under stress, is a protective mechanism associated in some way with tolerance to increasing levels of stress or whether these compounds are only indicators that a plant has been subjected to stress and are not protection-related.

Proline, a protein imino acid, has been reported to increase in plants during mild to severe stress (Kemble and MacPherson 1954). This increased content can be induced by drought, cold, or salt stress, and therefore appears to be a general stress response. Research on proline's effect on stress tolerance (Kemble and MacPherson 1954; Barnett and Naylor 1966; Singh and others 1972; and Stewart and others 1966) has led to speculation that proline acts as an osmoticum to reduce water loss through evapotranspiration or that it is used as a storage form of organic nitrogen available for rapid recovery and growth after relief from water stress.

Recent research indicates the actual function of proline during water stress may be to stabilize enzyme structure against heat denaturation (Nash and others 1982). This would result in the protection of critical metabolic pathways needed for plant recovery and growth after water stress.

The work of Paleg and others (1981) and Nash and others (1982) in Australia has shown that at temperatures of 38-54°C proline can protect enzymes from heat denaturation.

Atriplex canescens (Pursh)[Nutt.]does not accumulate large quantities of free proline during moisture stress (Cress 1982). It was therefore of interest to determine whether greater concentrations of free protein amino or imino acids occur during moisture stress. Several protein amino and imino acids have been shown to accumulate in plant tissue during moisture stress. Total asparagine accumulation is second only to proline during moisture stress (Thompson and others 1966).

Also of interest in moisture stress studies are reports of stress-induced reduction in numbers of polysomes (Hsiao 1970); reductions possibly correlated to the observed changes in free amino acids during moisture stress.

METHODS

Atriplex canescens seed were germinated in soil in 1-quart plastic pots in a greenhouse. Soil was maintained at field capacity during germination at 34-39°C days and 27-28°C nights. The soil for the study, collected from the Burnam Mine in northwestern New Mexico, was a composite of the A and B horizons. Fifteen days after seedling emergence, water was withheld from plants in the stress treatment. Control plants were watered regularly to prevent drying of the soil. At the end of 7 additional days, both control and stressed plant materials were analyzed. All shoots in each pot (10 to 15 plants per pot) were composited into one sample and the fresh weight measured. The moisture content of the soil on an ovendry basis was also determined

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at the time of harvest. For free amino acid analysis, the composited samples were suspended in methanol: chloroform: water (12:5:3) and disrupted in a Sorvall Omnimixer.

For free amino acid analysis, the amino acids were extracted from the composite samples, converted to their Phenythiohydantoin (PTH) derivatives, and analyzed on a Hewlett-Packard 1084B Liquid chromatagraph using an Altex Ultrasphere ODS (PTH) column (Moser and Rickli 1979). The study was done twice with three replications per treatment. For the nucleotide analysis, the individual plants (either moisture stressed or nonstressed) were extracted and the nucleotides analyzed on the 1084B Chromotograph using a Bio-Sil TSK 1EX-540 DEAE column. The nucleotide study was performed twice with four determinations per treatment. Statistical comparison of treatments was accomplished using the t-test. Significance was assured at $p=0.05$.

RESULTS AND DISCUSSION

The soil water content for the stressed treatment was 1.9 + 0.2 percent, and for the nonstressed pots 6.5 + 0.4 percent. Based on the ceramic plate method of soil water potentials, the osmotic potential of the stressed and nonstressed soil was -5.5 and -0.06 MPa respectively based on the soil water content.

The changes in free amino and imino acids during the 7 days of water stress are shown in table 1. Of the amino acids (cysteic, aspartic, glutamic, serine, tyrosine, and tryptophan), only glutamic acid decreased significantly with stress. It decreased from 12 µmol. per gram fresh weight to a nondetectable level. Asparagine, proline, and methionine all increased under water stress, but only asparagine showed a significant increase--from 16 to 30 µmol. per gram fresh weight. Glutamine, glycine, alanine, arganine, and phenylalanine were all present at concentrations of less than 0.01 µmol. per gram fresh weight; concentrations were barely detectable and therefore not quantified. Threonine, histidine, hydroxyproline, valine, isoleucine, leucine, and lysine were not detectable.

Contents of the free guanosine nucleotides (table 2), mono-, di-, and tri-phosphates, decreased in the moisture stressed plants. Only the decrease in guanosine 5-triphosphate was significant. The decrease in total guanosine nucleotides was 32 percent.

The pathways for biosynthesis of the nucleotides are shown in fig. 1. The important intermediates are glutamate, glutamine, and aspartate. Of these three amino acids, only glutamate significantly decreased in the pool of free amino acids during water stress. It is the key branch point for the flow of carbon from the tricarboxilic acid (TCA) cycle via 2-oxyglutarate to the nucleotides during their biosynthesis. The increase in asparagine from 16 to 30 µmol. per gram fresh weight during the stress period shows one possible product to which the carbon flow was channeled during water stress.

The decrease in polysomes during water stress has been well documented (Hsiao 1970; Morilla and others 1973), but a direct cause-effect relationship has not been demonstrated. The requirement of guanosine 5-triphosphate for the binding of the ribosomes to messenger RNA, and thus the formation and maintenance of polysomes, suggests that a loss of guanosine 5- triphosphate due to water stress would result in a loss of polysomes. The reduction in glutamate with the resulting loss of guanosine nucleotides, particularly guanosine 5-triphosphate, is therefore suggested as one direct cause of the loss of polysomes during water stress.

CONCLUSIONS

Considerable research has addressed the question of what mechanism regulates the biosynthesis of protein during water stress. The present study on changes in free amino acids and nucleotides during water stress in A. canescens suggests that during water stress the biosynthesis of protein is inhibited due to a loss of polysomes when the carbon necessary for the synthesis of guanosine tri-phosphate is channeled into asparagine.

Since guanosine tri-phosphate is necessary for the initiation step in the formation of the polysomes which synthesize proteins it is likely that their loss is the direct cause of the cessation of protein synthesis during water stress.

ACKNOWLEDGMENT

The author appreciates the cooperation of the U.S. Department of Interior, Office of Surface Mining, in conducting this research.

Table 1.--Changes in content of free amino acids in <u>Atriplex canescens</u> in water stressed versus nonstressed shoots.

Amino acid	Nonstressed	Stressed 7 days
	---------- µmol./g fresh weight ----------	
Cysteic	[1]0.47 ± 0.30	0.27 ± 0.07
Aspartic	0.12 ± 0.16	0.02 ± 0.01
Glutamic	[2]12.11 ± 9.76	(3)
Serine	5.21 ± 4.33	2.11 ± 0.90
Tyrosine	0.42 ± 0.10	0.07 ± 0.03
Tryptophan	4.03 ± 2.72	1.08 ± 0.53
Asparagine	[4]16.24 ± 3.18	30.24 ± 6.90
Proline	0.08 ± 0.04	0.11 ± 0.02
Methionine	0.03 ± 0.02	0.06 ± 0.04
Glutamine	(4)	(4)
Glycine	(4)	(4)
Alanine	(4)	(4)
Arganine	(4)	(4)
Phenylalanine	(4)	(4)
Threonine	(3)	(3)
Hydroxy proline	(3)	(3)
Valine	(3)	(3)
Isoleucine	(3)	(3)
Lysine	(3)	(3)
Leucine	(3)	(3)

[1]Means and standard deviations of 6 determinations.

[2]The nonstressed treatment is significantly different from the stressed treatment at the p=0.05 level using the t-test.

[3]Present at concentration of less than 0.01 µmol. per gram fresh weight (not quantifiable).

[4]Not detectable.

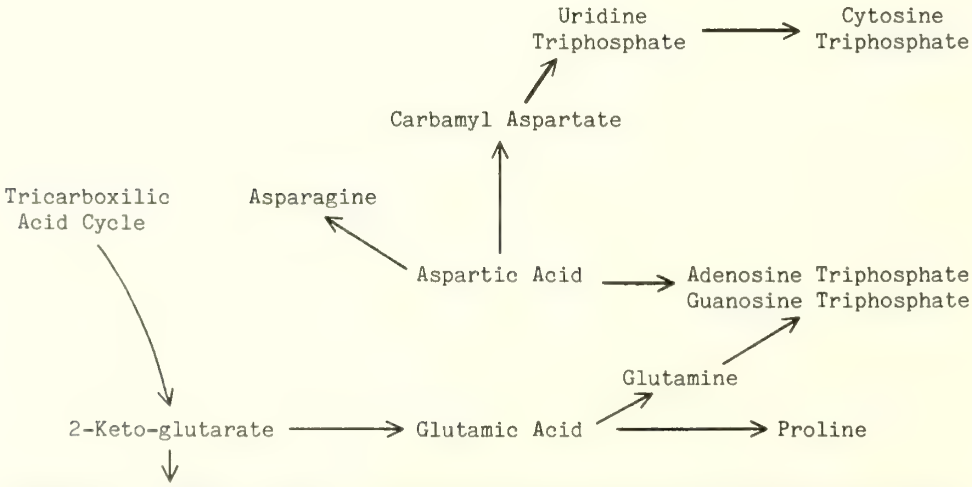

Figure 1.--The biosynthesis of the nucleotides from the TCA-cycle via their amino acid precursors.

Table 2.--Changes in content of free guanosine nucleotides in *Atriplex canescens* water stressed versus nonstressed shoots.

Nucleotides	Nonstressed	Stressed 7 days
	------------ µmol./g fresh weight	------------
Guanosine mono-phosphate	[1]9.05 ± 2.14	7.19 ± 2.13
Guanosine di-phosphate	[2]5.17 ± 1.37	3.44 ± 1.70
Guanosine tri-phosphate	[2]5.99 ± 0.89	2.99 ± 1.32
Total guanosine nucleotides	[2]20.21 ± 2.69	13.62 ± 2.52

[1]Means and standard deviations of eight determinations.

[2]The nonstressed treatment is significantly different from the stressed treatment at the p=0.05 level using the t-test.

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APPLICATION OF A WATER-BALANCE, CLIMATE MODEL FOR RESEARCH AND MANAGEMENT IN A DESERT-SHRUB COMMUNITY

J. Ross Wight

ABSTRACT: This paper discusses research and management applications of a model that simulates the soil water and soil temperature regimes, evaporation, and transpiration on a daily basis. The ratio of actual to potential transpiration provides an index of annual growing conditions based on soil water availability and evapotranspiration demand. This index can be used to compare growing conditions among years or among sites, account for the effects of climate in monitoring changes in plant communities, or evaluate treatment effects. Long-term simulations are possible. Simplicity enhances the model's application.

INTRODUCTION

Rangeland models are becoming increasingly important as research and management tools. They provide a systematic way of synthesizing and organizing information. They enhance the analysis and understanding of complex systems. Where models satisfactorily mimic the real world, effective research can be accomplished by performing experiments on the models rather than in the field. Through the process of simulation, variables such as soil water and soil temperature can often be estimated with sufficient accuracy to preclude the need for routine field measurements. As models are able to simulate the processes within an ecosystem, they also become effective tools for resource managers.

Rangeland models vary in complexity and resolution of output. They range from comprehensive ecosystem models such as ELM (Innis 1978), ELMAGE (Pendleton and others 1983), and SPUR (Wight 1983), to models such as ERHYM (Wight and Neff 1983) that consider the range as a monoculture and predict total herbage yield on the basis of water stress. The amount of information needed and complexity of operation are directly related to the complexity of the model.

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This paper discusses ERHYM, a physically-based model that is relatively simple to operate, and its application to problems of research and management. While only ERHYM will be discussed in this paper, its application to problems of research and management is typical of predictive models, and its application to desert-shrub communities is essentially the same as for other plant communities.

MODEL DESCRIPTION

The model discussed in this paper has been described by Wight and Hanks (1981), and Wight and Neff (1983). It is site-specific and operates on a daily time-scale. Inputs include an estimate of potential evapotranspiration (ET); daily precipitation; a transpiration coefficient; parameters for calculating a relative growth curve; and the initial soil water content, field capacity, and wilting point for each soil layer. Potential ET is calculated from daily solar radiation and average air temperatures (Jensen and Haise 1963). The transpiration coefficient can be estimated from the peak standing crop as described by Wight and Neff (1983). The relative growth curve is simply the seasonal change in live standing phytomass based on a scale of 0.0-1.0, where 1.0 represents peak standing crop.

Model outputs, calculated on a daily basis, include potential transpiration (T_p), actual transpiration (T_a), potential soil evaporation, actual soil evaporation, and soil water content by soil layer. These outputs can be mixed in various combinations to provide other information such as actual and potential evapotranspiration (ET) and T_a/T_p.

MODEL APPLICATIONS

Model outputs applicable to research needs include daily soil water content, ET, T_a/T_p, and soil temperatures. Figures 1, 2, and 3 show comparisons of field-measured and model-predicted values of soil water content, ET, and soil temperature, respectively, for a sagebrush dominated range site in southwestern Idaho. In general, there is good agreement between the model-predicted and field-measured values. Some of the discrepancies in the soil temperature and comparisons are due to the fact that the model-

predicted values represent daily means, and the field-measured values represent single, midday readings. Variables such as ET, T_a/T_p, and soil temperature are directly related to plant growth, and the availability of accurate model-predicted values can often reduce the need for field measurements, thus reducing both labor and instrumentation expenses.

A yield index, expressed as T_a/T_p, provides an effective means of quantifying soil water-precipitation-temperature relationships as they affect plant growth. T_a/T_p is generally better correlated to plant growth than either precipitation or combinations of precipitation and soil water because it also takes into account the evaporative demand and the distribution of water stress throughout the growing season. A T_a/T_p value of 1.0 indicates that water was nonlimiting during the growing season and that the yield should be the potential maximum for that site. Wight and Hanks (1981) reported a linear relationship between T_a/T_p and peak standing crop. They also found that T_a/T_p was more closely correlated to herbage yields than either T_a or ET.

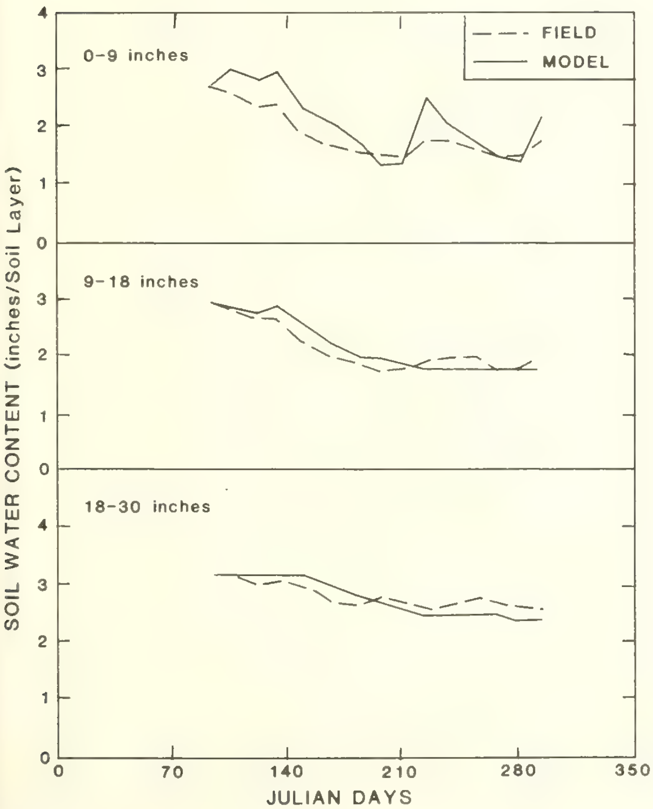

Figure 1.--Field-measured and model-predicted soil water profiles for a sagebrush-grass range site in southwestern Idaho, 1979.

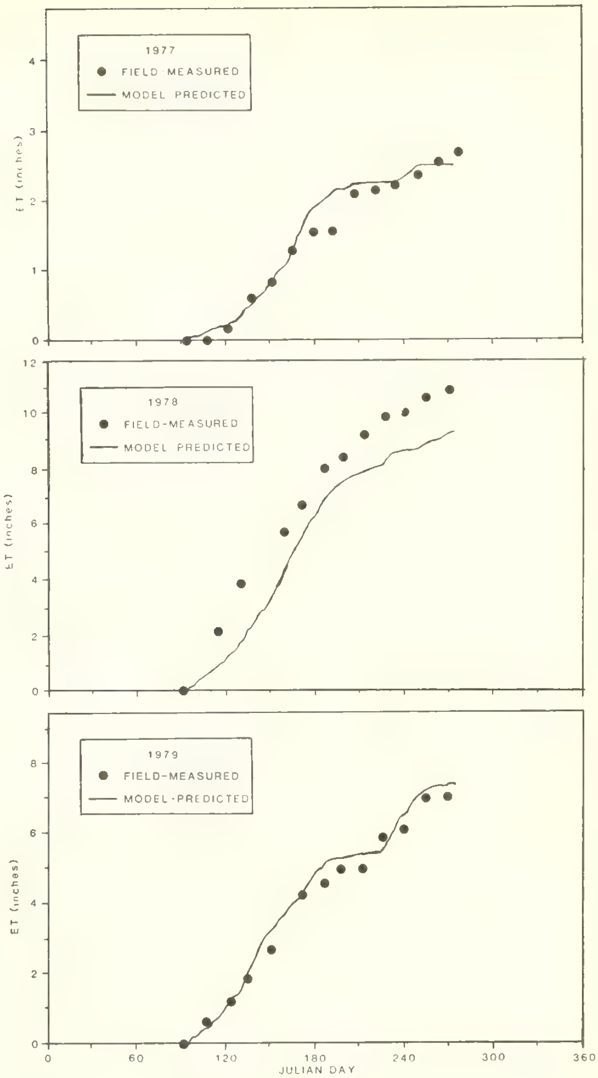

Figure 2.--Field-measured (from soil water and precipitation data) and model-predicted cummulative ET for a sagebrush-grass range site in southwestern Idaho.

The use of yield indices to quantify growing seasons in terms of water stress provides a means for comparing research results among sites and among years by removing the confounding effects of climate. For example, forage production from a wet year can be compared with forage production from a relatively dry year by normalizing the data on the basis of a yield index. Assuming a linear relationship between the yield index and yield, 300 lb/acre (336 kg/ha) yield produced in a growing season with a yield index of 0.5 is comparable to a 600 lb/acre (672 kg/ha) yield produced in growing season with a yield index of 1.0. The difference of 300 lb/acre (336 kg/ha) between growing seasons can be accounted for by climatic effects rather than treatment or management effects.

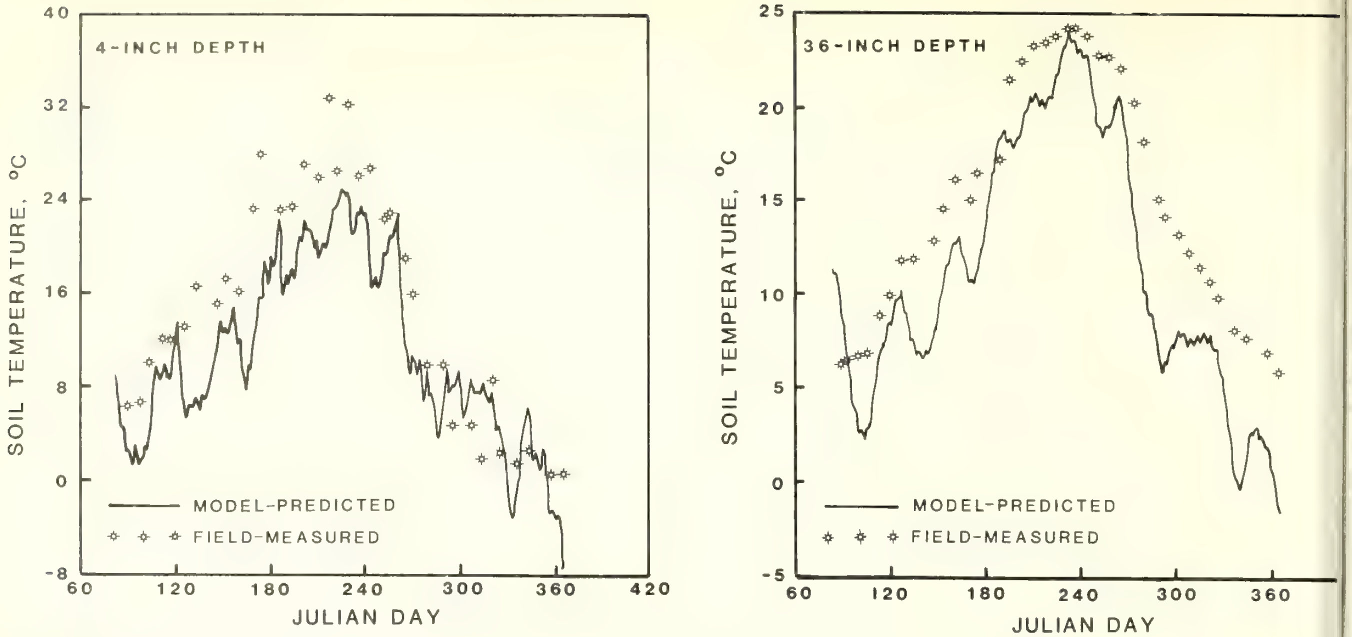

Figure 3.--Field-measured and model-predicted soil temperature profiles for 4-inch and 36-inch depths, respectively, for a sagebrush-grass range site in southwestern Idaho, 1981.

There are three areas in which models such as this can be directly applied to management: (1) prediction of annual forage production with real time data, (2) monitoring forage yield as an indication of trend, and (3) forecasting herbage production. Using the relationship actual yield/potential yield = T_a/T_p, peak standing crop for a given site can be readily calculated as the product of the T_a/T_p yield index and the potential yield of that site. The potential yield of a site is the yield that would occur on that site in its present condition, when water was nonlimiting. It does not refer to potential yields attainable with enhancements such as fertilization or reseeding. Table 1 and figure 4 show the relationships between the yield index and field-measured yield values for a sagebrush-grass and mixed prairie range site, respectively. The model has proved reasonably effective for mixtures of perennial grasses, shrubs, and forbs, but may be ineffective for predicting yields of annual plants where yields are directly related to varying plant populations. It has no mechanism to account for seedling establishments.

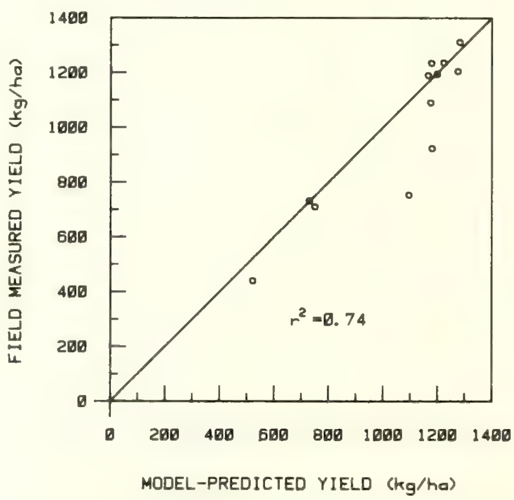

Figure 4.--Relationship between field-measured and model-predicted herbage yields for 1967-78, Sidney, Mont. (Wight and Hanks 1981)

Table 1. Comparison of model-predicted and field-measured yields for a sagebrush-grass range site in southwestern Idaho

Year	Model-predicted	Field-measured
1976	731	582
1977	286	307
1978	731	934
1979	717	780
Mean	616	651

For determining trend, the model-calculated yield index can be used to normalize data from succeeding years to remove the variability due to climate. This is demonstrated in figure 5a, where field-measured and model-predicted yields are plotted for a 10-year period. There is a wide variation in field-measured yields. This reflects climate and possibly management effects; no trend is apparent. The variation in model-predicted yields reflects only the climatic effects. Thus, the differences in field-measured and model-predicted yields can be used to indicate management induced trend. In figure 5b, the annual ratio of field-measured/model-predicted yields became increasingly less than 1.0 indicating a downward trend.

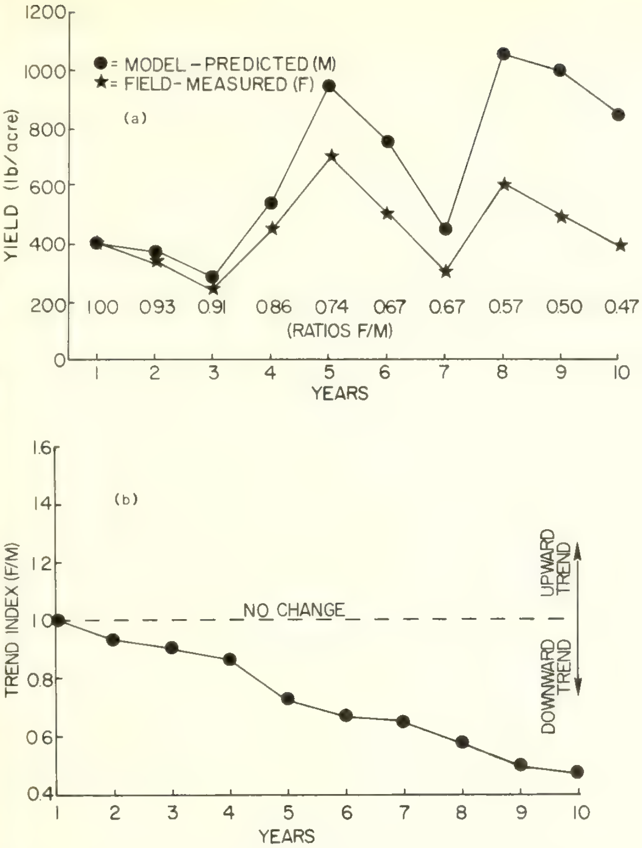

Figure 5.--(a) Hypothetical field-measured and model-predicted yields and (b) the use of their ratios (F/M) to determine management induced trend.

Yield indices can be used in conjunction with long-term weather records or a stochastic weather generator such as that used in SPUR (Wight 1983) to forecast the current year's herbage production at the beginning of the growing season (Wight and others 1984). By using the current year's initial soil water content and the daily precipitation and mean temperatures from past weather records, a yield index can be calculated for each year of the weather record. This results in yield indices that represent only variations in weather. The indices are normally distributed. A mean, with confidence intervals, can be calculated as the current year's yield forecast where yield is the product of the mean yield index (T_a/T_p) and the yield potential for that site. Using the standard deviation as the confidence interval, we establish a 68 percent probability that the current year's actual yield will be within a standard deviation of the forecasted yield. Yield forecasts can be updated periodically during the growing season by using the current year's weather records up to the date of forecast and past weather records from that date to peak standing crop.

With the development of comprehensive management models such as SPUR, management options such as grazing intensity or improvement practices such as seeded pastures can be evaluated in terms of plant and animal response, economic returns, and runoff and erosion impacts through the process of simulation. The future will, no doubt, see more application of modeling technology in rangeland research and management.

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THE EFFECT OF SALINITY ON THE IONIC CONTENT AND WATER RELATION OF *ATRIPLEX TRIANGULARIS* WILLD.

S. H. Karimi and I. A. Ungar

ABSTRACT: Survival and growth in saline environments is dependent upon plants reaching a favorable water balance. Measurements under various salinity conditions indicate that *Atriplex triangularis* Willd. maintains a more negative water potential, osmotic potential, and shoot xylem pressure potential than its root media. Root xylem pressure potentials were always less negative than those of the shoot. Highest leaf turgor pressure was achieved in moderately saline conditions; increased salinity decreased the leaf pressure potential. Accumulation of Na+ and Cl- ions in the leaves is probably the chief mechanism for lowering the leaf osmotic potential. Less negative shoot xylem osmotic potential suggests that leaves may remove ions rapidly from the xylem sap.

In order to cope with the high salt concentrations in its natural environment, *A. triangularis* appears to employ the following strategies: first, low root xylem pressure potential indicates the root regulates ion influx into the plant in higher salinities; second, abscission of very old leaves, which appear to have Na+ and Cl- ion concentrations similar to those of young leaves, serves as a mechanism for the removal of ions; third, functional salt hairs are found only in young leaves and serve as a mechanism for the removal of excess ions; and fourth, increased succulence appears to be the principal mechanism for osmoregulation in mature leaves.

INTRODUCTION

A number of attempts have been made to classify halophytes based on their mechanism of salt tolerance (Waisel 1972; Albert 1975; Caldwell 1974). Three categories are widely used: salt accumulators, salt evaders, and salt excluders (Flowers and others 1977; Schirmer and Breckle 1982). Although there are halophytes which may fit each category, distinctions among these groups are difficult to sustain (Osmond and others 1980). *Atriplex* species exhibit a number of anatomical and physiological features that facilitate the survival of the plant in saline environments.

Mineral accumulation in aerial organs is a common phenomenon observed in the genera that inhabit saline environments. Inorganic ions account for over 25 percent of leaf dry weight in a number of *Atriplex* species growing in saline media (Ashby and Beadle 1957; Wood 1937). Accumulation of high quantities of ions can produce a negative leaf osmotic potential, thus assuring a water potential gradient. Such high concentrations of minerals are likely to have an adverse effect on plant growth and development (Flowers and others 1977). Halophytes employ two mechanisms to avoid the detrimental effects of high tissue mineral content: first, dilution of mineral concentration in leaves is achieved through increased succulence (Sharma 1982; Gale and Poljakoff-Mayber 1970); and second, salt excretion regulates the electrolyte content of leaves (Liphschitz and Waisel 1982).

A common anatomical feature shared by all *Atriplex* species studied so far is the presence of vesiculated epidermal hairs on leaves. These structures, which are also called salt hairs, salt bladders, and epidermal trichomes, play an important role in the overall salt economy of these taxa (Schirmer and Breckle 1982). About half of the leaf minerals may be contained in these structures.

Some halophytes are also known to have developed avoidance mechanisms (Waisel 1972). Avoiders are very selective in their ion uptake and, as a result, maintain a low internal concentration of minerals (Scholander and others 1966). However, recent studies indicate that selective uptake of minerals appears to be important in ion regulation of some *Atriplex* species (Breckle 1974; Ruess and Wali 1980; Richardson 1982).

Atriplex triangularis Willd., an annual halophyte, grows successfully in soils with salinity levels approaching sea water (Riehl and Ungar 1983; Ungar 1977). Black (1956) studied the ionic relations of *A. triangularis*, and found a higher concentration of Cl- in the root than in the shoot throughout the range of salinities tested. Root Na+ concentration was also higher in most salinities, suggesting that *A. triangularis* may hold back the salts in the root. In contrast, Osmond and others (1980) found a lower concentration of these ions in the root than in the shoot. These data agree with the electrophysiological measurements of Anderson and others (1977) and ion probe data of Kramer and others (1978).

The objectives of the present research were to determine the mechanisms by which *A. triangularis* plants adjust to salt stress. The effect of salinity on the ionic content, water potential, osmotic potential, pressure potential, and succulence of plant organs was determined.

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MATERIALS AND METHODS

Growth

Atriplex triangularis seeds were collected in October 1980 from a salt marsh near Rittman, Ohio, and refrigerated until used. Seeds were sown in Flint-Lock sand in a growth chamber set for a 12-hour day at 25° C and a 12-hour night at 15° C. Four leaf stage seedlings (1.5 to 2.5 cm long) were transferred to plastic quart containers. The exteriors of the containers were painted black and covered with aluminum foil to prevent algal growth. The culture solution used was Hoagland and Arnon #2. Salinity was increased in 0.5 percent NaCl increments every 48 hours, to allow time for acclimation, until desired salinity was attained. Solutions were continuously aerated with air pumps. Nutrients and salts were replaced weekly. Plants were grown in an M13 Environmental Growth Chamber set for a 16-hour day at 25° C and an 8-hour night at 15° C. Light intensity was 1400 foot-candles; relative humidity was 73 percent. All of the experiments were performed on 13-to 15-week-old plants.

Water Relations

Xylem pressure potential was measured with a pressure chamber (Soil Moisture Equipment Corp. Model 3005). The stem was cut close to the root with a sharp razor blade, and the cut end was then fitted through the lid of the chamber. The balancing pressure at which sap appeared at the cut end was recorded as xylem pressure potential. Bubbling that occurred at pressures below 0.1 MPa and commenced with elevated pressure was ignored, as recommended by Phillips (1981). After wiping the cut end clean, a filter paper disk 4 mm in diameter was saturated with expressed sap and used to determine xylem sap osmotic potential. Since it is believed that only the earliest effluxes of sap represent intracellular osmotic potential (Barrs 1968), special effort was made to use only this portion of the sap for the measurements.

Leaf water potential, leaf osmotic potential, and xylem pressure potential were measured with a Wescor HR-33T dew point microvoltmeter. A leaf punch, 4 mm in diameter, was removed. This disk was either homogenized with a glass rod to determine osmotic potential, or left intact to determine water potential. Homogenized leaf tissue, leaf disk, or saturated filter paper disk was sealed promptly in a Wescor C52 sample chamber. Equilibration times were 7 and 30 minutes for osmotic potential and 30 minutes for water potential.

Leaf Age and Salt Bladder

Leaves from the three uppermost nodes were designated as young leaves; leaves from the three lowest nodes were designated as mature leaves. Salt bladders were removed from one group of leaves and these leaves were subsequently rinsed briefly with distilled water and blotted dry before use. In a second group, leaves were briefly rinsed to remove the surface salt prior to use.

Ion Analysis

Fresh tissue samples were weighed and oven dried at 80° C to a constant dry weight. Tissue water content was calculated as the difference between the fresh and dry weight measurements. Dried samples were ashed overnight at 450° C in a Thermolyne 1400 muffle furnace. Ash was dissolved in known amounts of double distilled water and used for analysis. Concentrations of Na^+ and K^+ were determined by flame emission and Mg^{2+} and Ca^{2+} by atomic absorption using a Perkin-Elmer model 360 atomic absorption spectrophotometer. Chloride concentration was estimated with a Beckman specific ion electrode using NaCl as the standard. The intracellular concentration was estimated from tissue water content.

Statistical analysis systems on an IBM 370 computer were used to analyze these data.

RESULTS

Water Relations

Leaf water potential, osmotic potential, and root and stem xylem osmotic potential became more negative as water potential of the culture solution decreased (figs. 1,2,3). These values all

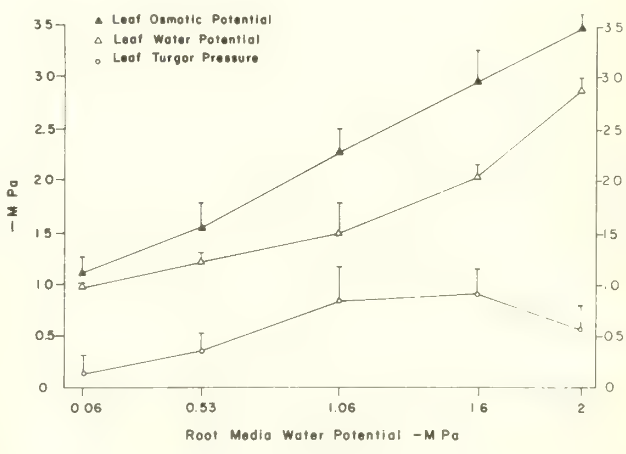

Figure 1.--Water potential (-MPa), osmotic potential (-MPa), and turgor pressure (MPa) for leaves from Atriplex triangularis plants grown in 0.5 strength Hoagland and Arnon No. 2 nutrient solution. Sodium chloride was added to attain media water potential. Data = mean $\pm$ S.E.M.

showed significant correlation with media conductivity and remained more negative than the media water potential. Progressive increase in media salinity resulted in more negative root xylem pressure potential. This value was usually less

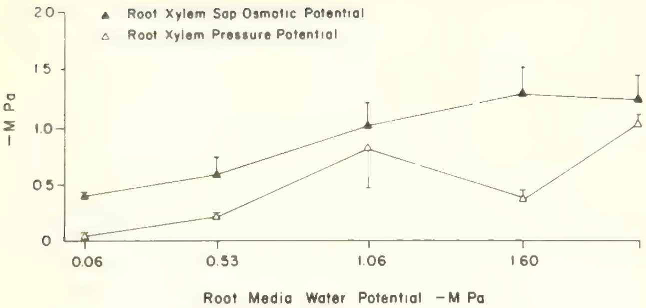

Figure 2.--Xylem pressure potential and xylem osmotic potential for roots of Atriplex triangularis plants grown in 0.5 strength Hoagland and Arnon No. 2 nutrient solution. Sodium chloride was added to attain the desired media water potential. Data = mean ± S.E.M.

negative than the media water potential, leaf water potential, leaf osmotic potential, and stem xylem pressure potential. Control plants had a root osmotic potential about seven times more negative than the medium, indicating an active ion uptake by these plants. In the two intermediate salinities, root osmotic potential was similar to the bathing solutions but lower values were found in the two highest salinities.

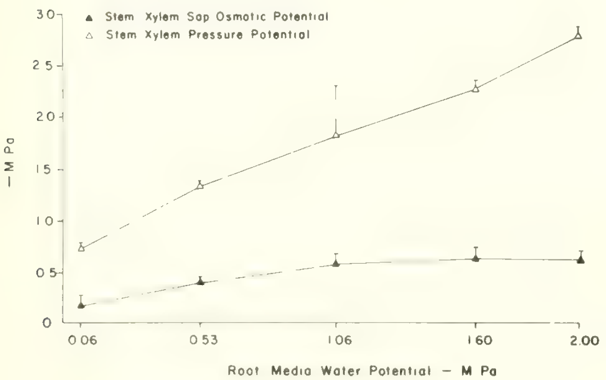

Figure 3.--Xylem pressure potential and xylem sap osmotic potential of shoots from Atriplex triangularis plants grown in 0.5 strength Hoagland and Arnon No. 2 nutrient solution. Sodium chloride was added to attain media water potentials. Data = mean ± S.E.M.

Shoot xylem pressure potential decreased with the addition of salt up to -1 MPa and then remained unchanged in higher salinities.

The difference between leaf water potential and osmotic potential was calculated as an estimate of leaf pressure potential. This is thought to be more reliable than calculating the difference between xylem pressure potential and leaf osmotic potential since the latter can give false values (Roy and Mooney 1982). Non-saline plants had the lowest leaf pressure potential. While addition of salt to the media improved leaf pressure potential to some extent, the beneficial effect of salt was limited to intermediate salinities. Data for osmotic potential of leaves of different ages is presented in figure 4. Epidermal salt hairs were removed to

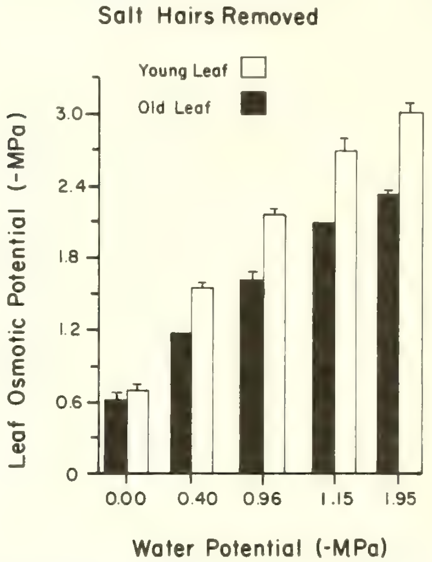

Figure 4.--Osmotic potentials for leaves of Atriplex triangularis with salt hairs removed. Data = mean ± S.E.M.

avoid the errors that can result from mixing leaf minerals with the ions contained in the bladders. Both young and mature leaves maintained a more negative osmotic potential than external water potential in all treatments. Young leaves maintained a more negative osmotic potential than mature leaves in the range of salinity tested.

Succulence

Leaf succulence was estimated by determining the fresh weight:dry weight ratio. Increase in salinity led to a gradual increase in young leaf succulence. Control plants were least succulent; plants from the highest salinity had the highest succulence (fig. 5). The relationship between salinity and succulence was, however, less direct for mature leaves. Regardless of media salinity, mature leaves from all salt treated plants were more succulent than leaves from control plants. Variation in salinity did not affect succulence. Mature leaves of salt treated plants were consistently more succulent than young leaves.

Correlation Coefficient Between the Components of Water Relation

Results presented in table 1 are helpful in assessing various techniques used to investigate the plants' water status. Both dew point hygrometer and pressure bomb measurements show a significant correlation with media conductivity. Values for xylem pressure potential also demonstrate a correlation with other components. Leaf pressure potential estimates differ from other parameters in that they are not significantly correlated with media conductivity and other components of plant water status.

Table 1.--Correlation coefficient (r) between leaf water potential (Ψ), leaf osmotic potential (π), stem xylem pressure potential (XYPP), stem xylem sap osmotic potential (XYπ), root xylem pressure potential (XYPP), root xylem sap osmotic potential (XYπ), leaf pressure potential (PP), medium water potential (Ψ). P = level of significance.

		Leaf π	Leaf PP	Medium salinity	Stem XYPP	Stem XYπ	Root XYPP	Root XYπ
Leaf Ψ	r	0.88	-0.13	0.87	0.84	0.75	0.71	0.54
	P	0.0001	0.4952	0.0001	0.0001	0.0001	0.0001	0.0048
Leaf π	r		0.36	0.94	0.73	0.71	0.64	0.70
	P		0.0500	0.0010	0.0001	0.0001	0.003	0.0001
Leaf PP	r			0.25	-0.07	0.06	-0.07	0.46
	P			0.1852	0.7300	0.7400	0.7300	0.0177
Medium	r				0.77	0.73	0.69	0.63
Salinity	P				0.0001	0.0001	0.001	0.0006
Stem	r					0.77	0.76	0.55
XYPP	P					0.0001	0.0001	0.0048
Stem XYπ	r						0.66	0.68
	P						0.0001	0.0001
Root XYPP	r							0.49
	P							0.0104

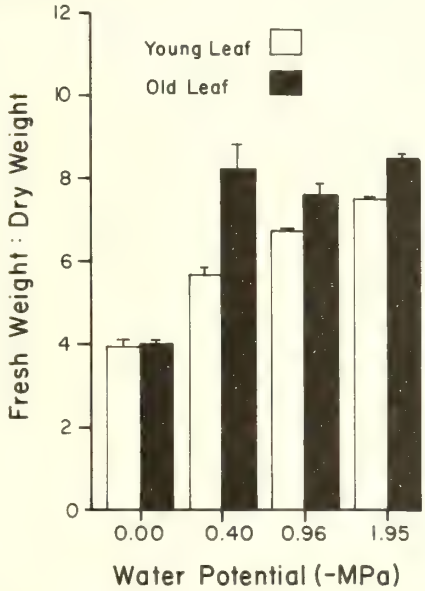

Figure 5.--Fresh weight:dry weight ratios for young and old leaves from Atriplex triangularis plants. Data = mean ± S.E.M. LSD (0.05) for young leaves = 2.5, LSD (0.05) for old leaves = 2.7.

Ion Accumulation

Concentrations of Na^+ and Cl^-, calculated on dry weight or tissue water content, increased in all organs as a response to a higher concentration of salt in the root media (tables 2,3, and 4). The Cl^- content generally increased less than Na^+ content. Salt content of mature leaves appeared to be twice as high as that of young leaves when considered on a dry weight basis. However, the concentration of salt in both young and mature leaves was similar. This could be due to the increased succulence of mature leaves that causes a dilution of salt. Young leaves contain more Na^+ and Cl^- than mature leaves when bladders are intact. This is apparently due to the ions accumulated in these organs, since no difference was observed in leaves of different ages after bladder removal. The difference between the ion content of leaves with and without bladders is expressed as an estimate of ions secreted by the plant (tables 2,3, and 4). This difference is primarily present in young leaves. Removal of the bladders did not affect the ion content of mature leaves. Abscised leaves contained a high concentration of Na^+ and Cl^-. Concentration of these ions in stems was similar to that in the leaves, but concentrations of Na^+ and Cl^- in roots were always lower than in the other organs.

Concentrations of K^+, Ca^{2+}, and Mg^{2+} showed a similar pattern (tables 5 and 6). Concentrations were highest in the control plants, however, after an initial reduction, ion concentration remained relatively unchanged in response to increased salinity. Young leaves contained more K^+, Ca^{2+} and Mg^{2+} than mature leaves. All organs analyzed had a higher concentration of Mg^{2+} than Ca^{2+}. The ratio of K^+:Na^+ decreased with an increase in medium salinity, from root to shoot, and with leaf aging. Older leaves had higher Na^+ and Cl^- concentrations than young leaves (tables 6 and 7).

DISCUSSION

A. triangularis responded to increasing media salinity by lowering the leaf water potential, leaf osmotic potential, and stem xylem pressure potential. Similar results were obtained under field conditions by Ungar (1977) in A. triangularis

Table 2.--Concentration of Na+ (meq L^{-1}) present in various organs of Atriplex triangularis grown in 0.5 strength Hoagland and Arnon No. 2 nutrient solution to which NaCl was added to obtain desired salinity. Data = mean ± S.E.M. Young and mature leaves were analyzed with either bladders intact (A) or removed (B). C = A-B is an estimate of Na+ in bladders; LSD = least significant difference.

NaCl (meq L^{-1})		Young leaf	Mature leaf	Abscised leaf	Stem	Root
0	A	95±28	39±8	120±2.5	7.1±1.3	28±4
	B	59±15	41±1	---	---	---
	C	36	2	---	---	---
86	A	400±37	353±71	958±66	519±157	113±26
	B	342±28	381±39	---	---	---
	C	58	---	---	---	---
258	A	811±102	547±49	2347±1275	523±21	338±15
	B	469±50	469±34	---	---	---
	C	342	78	---	---	---
517	A	1001±121	792±22	1893±568	781±75	411±74
	B	691±88	809±55	---	---	---
	C	310	---	---	---	---
LSD (0.05)	B	282	146	2279	285	300

Table 3.--Concentration of CL- (meq L^{-1}) present in various organs of Atriplex triangularis grown in 0.5 strength Hoagland and Arnon No. 2 nutrient solution to which NaCl was added to obtain desired salinity. Data = mean ± S.E.M. Young and mature leaves were analyzed with bladders intact (A) or removed (B). C = A-B is an estimate of Cl- in bladders; LSD = least significant difference.

NaCl (meq L^{-1})		Young leaf	Mature leaf	Abscised leaf	Stem	Root
0	A	37±6	15±1	74±54	43±10	14±2
	B	30±7	14±1	---	---	---
	C	4	1	---	---	---
86	A	217±16	172±6	235±45	160±60	135±42
	B	183±28	215±26	---	---	---
	C	24	---	---	---	---
258	A	705±84	565±71	1306±588	466±33	224±45
	B	287±14	275±27	---	---	---
	C	428	290	---	---	---
517	A	937±113	631±22	1907±775	652±77	249±44
	B	705±99	679±88	---	---	---
	C	232	---	---	---	---
LSD (0.05)	B	240	122	1590	169	93

and by De Jong (1981) in A. leucophylla (Moq) Dietr. A negative shoot water potential relative to media salinity reflects the plant's ability to sustain a water potential gradient which assures the inward flow of water in diverse saline environments. This is achieved by mineral absorption and accumulation of organic compounds (Richardson and McKell 1980; Ruess and Wali 1980; Storey and Wyn Jones 1979). Atriplex triangularis maintains a relatively constant water potential gradient, about -1 to -1.5 MPa, more negative than the external solution. Halophytes adjusting their osmotic potential in this manner are commonly known as osmoconformers (Jefferies 1980; and Wyn Jones 1981).

Negative leaf osmotic potential found in control plants is similar to that found by Kaplan and Gale (1972) in A. halimus L. This is perhaps due to the higher concentrations of K+, Ca^{2+}, Mg^{2+} and oxalate, as reported by Osmond (1966). Leaf pressure potential was higher at intermediate salinities, possibly as a result of improved water balance with increased leaf ionic content. This agrees with Kaplan and Gale (1972) who found a higher leaf pressure potential in salt treated A. halimus.

In the past, several workers have experienced difficulty estimating the water potential of halophytes, when using the dew point technique, because of dissolving salt either from the salt

Table 4.--Concentration of K+ (meq L^{-1}) and ratio of K+/Na+ in various organs of Atriplex triangularis grown in 0.5 strength Hoagland and Arnon No. 2 nutrient solution to which NaCl was added to obtain desired salinity. Data = mean ± S.E.M. LSD = least significant difference.

NaCl (meq L^{-1})		Young leaf	Mature leaf	Stem	Root
0	K+	290±136	171±72	21.2±7	695±182
	K+/Na+	6.1±3.8	3.9±1.37	3.49±1.666	6±0.003
86	K+	82±2	33±8	59±8	103±20
	K+/Na+	0.21±0.017	0.09±0.005	0.13±0.033	1±0.071
258	K+	81±9	36±3	51±4	110±12
	K+/Na+	0.10±0.005	0.07±0.002	0.10±0.005	0.7±0.510
517	K+	36±5	30±3	19±3	49±4
	K+/Na+	0.04±0.005	0.04±0.003	0.02±0.002	0.1±0.027
LSD (0.05)	K+	200	119	9	42
LSD (0.05)	K+/Na+	5.6	2.3	2.7	1.2

Table 5.--Concentration of Ca++ and Mg++ (meq L^{-1}) present in various organs of Atriplex triangularis grown in 0.5 strength Hoagland and Arnon No. 2 nutrient solution to which NaCl was added to obtain desired salinity. Data = mean ± S.E.M. LSD = least significant difference.

NaCl (meq L^{-1})		Young leaf	Mature leaf	Stem	Root
0	Ca++	11.0±5.3	4.3±0.8	2.0±0.3	10.5±1.0
	Mg++	151.9±125.6	15.0±7.4	6.1±1.0	26.6±2.6
86	Ca++	2.0±0.5	1.1±0.7	0.4±0.1	4.6±1.2
	Mg++	6.8±1.9	3.5±1.8	3.5±2.1	7.3±6.1
258	Ca++	4.7±0.7	2.8±0.3	1.4±0.7	3.7±0.7
	Mg++	21.6±3.8	6.9±0.8	5.3±1.5	19.7±2.3
517	Ca++	4.6±0.7	2.1±0.1	3.4±1.3	5.8±0.6
	Mg++	10.5±1.0	7.1±1.3	8.4±1.5	11.1±9.4
LSD (0.05)	Ca++	8.0	1.9	2.4	2.4
LSD (0.05)	Mg++	144.4	12.3	5.1	22.2

excreting structures or discrete salt accumulating cells (Gale and Poljakoff-Mayber 1970). However the present study shows that the removal of bladders and subsequent rinsing of A. triangularis leaves are sufficient for obtaining accurate estimates of osmotic potential and water potential. A high degree of correlation observed between leaf osmotic potential and leaf water potential with stem xylem pressure potential suggests that both measurements are reliable indicators of plant water status. These data should facilitate further water relation studies of A. triangularis.

Root xylem pressure potential was used as an indirect estimate of xylem sap ion concentration, and there was a rather distinct pattern in response to varying media salinity. Root xylem pressure potential of control plants was nearly seven times higher than the external media, similar to the media in intermediate salinities, and less negative than the media in the highest two salinities. This may suggest that plants exert some control over the inward movement of ions at higher salinities, which seems to agree with the flux studies of Anderson and others (1977). They found that the concentration of Na+ was lower in A. triangularis root cells than in the external solution. This has raised the possibility that the permeability of A. triangularis root to Na+ is low and the Na+ that enters the root by passive diffusion is probably removed by active efflux. Kramer and others (1978) employing electron probe microanalysis technique, also found a low concentration of Na+ in the root of A. triangularis at 300 and 600 mM NaCl external solution (comparable with our treatment). This is an additional indication of a possible control over the inflow of Na+ at higher salinities. Kramer and others (1978) found that transfer cells developed in the root epidermis of A. hastata (triangularis) in response to salt treatment. They concluded that these cells excluded Cl- relative to media concentrations. Root ion regulation has been reported in A. canescens (Pursh) Nutt. (Richardson 1982) and A. falcata (M. E. Jones) Standley (Breckle 1974). This strategy may prove to be more widespread in Atriplex species than has been realized.

Salt hairs were restricted to young leaves and seem to serve the purpose of active salt excretion. Limitation of excreting organs to young

Table 6.--Concentration of Na+ and Cl- in Atriplex triangularis leaves expressed on a tissue water or dry weight bases. Data = mean ± S.E.M. LSD = least significant difference.

NaCl (meq L^{-1})	Ions	meq L^{-1}		μeq g^{-1} dry weight	
		Young leaves	Mature leaves	Young leaves	Mature leaves
0	Na+	32±2	41±4	150±13	454±101
	Cl-	30±7	15±12	140±36	155±22
86	Na+	343±28	381±39	2033±216	4401±568
	Cl-	183±28	215±26	1080±169	2522±451
258	Na+	469±50	469±37	2627±195	5553±733
	Cl-	287±14	275±30	1631±184	3194±204
517	Na+	691±88	809±55	3666±577	7425±676
	Cl-	705±99	679±88	3752±661	6236±876
LSD (0.05)	Na+	282	146	1670	2306
LSD (0.05)	Cl-	240	122	1398	1127

Table 7.--Summary of analysis of variance for Na+, K+, K+/Na+ ratio, Cl^-, Ca++ and Mg++ in Atriplex triangularis organs. All of the ion concentrations are based on tissue water content.

Dependent variable	SS	F	P	LSD
Na+ (meq L^{-1})	9210363.37	6.21	0.0013	57
K+ (meq L^{-1})	259339.30	8.62	0.0001	82
K+/Na+ Ratio	47.40	21.84	0.0001	
Cl- (meq L^{-1})	7911664.29	11.29	0.0001	393
Ca++ (meq L^{-1})	1019.15	4.48	0.0078	7
Mg++ (meq L^{-1})	33998.14	3.69	0.0184	45
Leaf succulence	22.55	9.26	0.0058	

leaves is not uncommon. Salt glands of Avicennia marina (Forsskal) Vierh. are reported to collapse as leaves age (Drenan and Berjak 1982). Mature leaves of A. triangularis use succulence as an alternative to bladders for internal adjustment of ions. A correlation between the reduction in Cl- content of bladder cells and leaf thickening has been reported for many Atriplex species (Osmond and others 1980).

A continuous higher concentration of Na+ and Cl- in leaves relative to the root media is an indication of the significant role that these minerals play in plant osmoregulation as found by Black (1960) and Delane and others (1982). The lower concentration of Cl- found in plant leaves in comparison with Na+ is in agreement with the other reports in the literature (Osmond 1966; Kramer and others 1978; Storey and Wyn Jones 1979). It has been proposed that oxalate is synthesized in Atriplex leaves in response to excess cations (Osmond 1967).

Expressed stem xylem sap had a less negative osmotic potential than the root osmotic potential, which is an indication of lower concentration of ions in the sap. This could be explained by the very efficient transport and active removal of Cl- ions from the root of A. triangularis (Anderson and others 1977). Concentrations of Na+ and Cl- were closely linked to media salinity. This is similar to findings of others (Black 1956; Greenway and others 1966; and Osmond and others 1980).

Concentration of Na+ and Cl- was lower in Atriplex roots than in shoots. This differs from results of Black (1956), but agrees with findings of Osmond and others (1980) and Greenway and others (1966). Thus, if there exists a mechanism for control of ion movement from the root to the shoot, these ions are unlikely to be stored in the root. Low concentration of Na+ has been found in the root of a number of Atriplex species growing in saline media (Osmond and others 1980; Greenway 1968).

Concentrations of less abundant nutrients, K+, Ca^{2}+, Mg^{2}+, are adversely affected by the presence of NaCl in the media, however, after the initial reduction in these ions, their level of absorption is maintained despite the increase in NaCl concentration. A similar reduction in K+ uptake in response to external salinity was reported by Black (1956) and Greenway and others (1966). Black (1956) attributed the high concentration of K+ in Atriplex leaves growing in nonsaline media to a luxury uptake by the plant. This additional K+ substitutes for Na+, which is low in the nonsaline media, and is thought to function as an osmoregulator rather than a nutrient. Negative osmotic potential of leaves in the nonsaline medium could be explained on this basis. Concentration of K+ is not reduced beyond a certain level since K+ is essential for the healthy functio of cytoplasm (Osmond and others 1980). Presence of NaCl is also linked to the reduced absorption of divalent cations in halophytes. Osmond (1966)

attributed the low concentration of Ca^{2+} in Atriplex species to high concentrations of Na+ which depressed the Ca^{2} uptake.

One of the interesting features of leaf aging was that mature leaves always maintained lower concentrations of K+, Ca^{2+} and Mg^{2+} than young leaves, whereas no such difference was observed for Na+ and Cl-. Removal of these essential ions from the mature leaves occurred prior to abscission. This, along with high concentrations of Na+ and Cl- in abscised leaves, raises the possibility that essential nutrients were withdrawn from mature leaves while Na+ and Cl- were left to be removed as leaves eventually abscised. Comparing the green and senescent leaves of a number of halophytes, Karmarkar (1982) reached a similar conclusion. While the senesced leaves contained higher Na+ and Cl-, concentrations of K+, Mg^{2+}, and P were lower than in green leaves. Albert (1974) studied a number of halophytes and found a gradual rise in leaf salt content while nutrients like N, P, and K+ were translocated into the growing young leaves. Greenway and others (1966) and Yeo (1981), using tracers, confirmed the immobility of salts in the mature leaves of halophytes. This is more significant when considering the apparent adverse effect of Na+ on the absorption of these nutrients.

The present study appears to suggest that A. triangularis contains several mechanisms for mineral regulation which, when used together, enable the plant to avoid potentially harmful concentrations of salt in its tissues. These mechanisms include: salt hairs which remove excess ions from young leaves; succulence which dilutes the ion content of leaf cells; abscission which removes organs containing high salt concentrations; and root ion flux regulation which apparently operates at high salinities. In spite of seemingly effective strategies that work in conjunction for ion regulation, plants accumulate considerable amounts of minerals. These minerals are likely to play a central role in the process of plant osmoregulation.

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SEASONAL LEAF NITRATE REDUCTASE ACTIVITY, NITROGEN AND NITRATE CONTENT, AND WATER RELATIONS OF ATRIPLEX CANESCENS IN THE NORTHERN CHIHUAHUAN DESERT

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ABSTRACT: Seasonal nitrate reductase (NR) activity of young, uppermost leaves of *Atriplex canescens* (Pursh) Nutt. (diploid genotype) growing *in situ* was maximal during reproductive growth. Because precipitation on the study site coincided with reproductive growth, higher NR activity during this period may have been due to new leaf growth and increased soil NO_3^- availability rather than the nitrogen sink in developing seeds. Seasonal leaf water content (percent) was significantly ($P<0.10$) correlated with NR activity. Stem xylem water potentials were not correlated with NR activity. Although thermal adaptation of NR would, in general, be advantageous for plants inhabiting a desert environment with widely fluctuating seasonal temperatures, there was no evidence to suggest that acclimation of NR occurs in *A. canescens* growing *in situ*.

INTRODUCTION

Perennial plants inhabiting the northern Chihuahuan desert are exposed to extended periods of drought, wide fluctuations in seasonal temperatures, and high solar insolation. These factors are intimately involved in regulating nitrate reductase (NR) activity. High temperatures rapidly inactivate NR (Onweunne and others 1971; Mattas and Pauli 1965), and water stress depresses NR activity through reduced synthesis of the enzyme (Morilla and others 1973). Irradiation is involved in both the synthesis (Hagemen and Flesher 1960) and maintenance (Klepper and others 1971) of NR. Of particular importance in a desert environment is the availability of soil NO_3^-, and its uptake and translocation to NR sites in canopy leaves. Since NR induction occurs in the presence of NO_3^-, the seasonal balance between leaf NR activity and NO_3^- levels may be critical in establishing reduced nitrogen concentrations of *Atriplex canescens* (Pursh) Nutt. plants during prolonged dry periods *in situ*. Optimal NR activity may occur only during a rather brief period following rainfall when new leaf growth is initiated and when more optimal soil- and plant-water relations permit increased leaf NO_3^- levels for NR induction.

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Harmer and Lee (1981) suggested that NR acclimates to low temperatures. It was not, however, evident whether their data support acclimation or, instead, an inhibition of NR under the colder growing temperature, thus leading to NO_3^- accumulation. The initial objective of the present study was to determine if NR is capable of thermal adaptation in *A. canescens* growing *in situ*. The second objective was to determine the seasonal NR activity, NO_3^- content, and reduced nitrogen levels of *A. canescens* growing *in situ* relative to leaf-water relations. A substantial increase in NR activity has been observed during the post-flowering reproductive growth period in *Phaseolus vulgaris* L. (Franco and others 1979) and a decline in NR activity occurred throughout a comparable period in *Glycine max* L. (Franco 1977; Harper and Hageman 1972) where there was no water stress. The final objective was to examine NR activity during reproductive growth *in situ* where soil water is often limited.

METHODS

Leaf samples (ca. 5 grams) from mature fourwing saltbush (*Atriplex canescens* [Pursh] Nutt.) plants growing *in situ* near Las Cruces, N. Mex. (diploid [2n=18] ca. 32° 37' N 106° 45' W were collected at approximately 25 day intervals from August 1981 through November 1982 for NR activity assays and nitrogen and NO_3^- content determinations. All samples were collected within 1.5 hours prior to solar noon except for September 25 and 26, 1981, when samples were collected prior to sunrise, at approximately solar noon, and 4.5 hours after solar noon. Sample collection days were cloudless except for the partly cloudy day of September 11, 1981. Young, fully expanded leaves located on the south side and top of the plant canopy were collected for subsequent analyses. The same four to six plants were used throughout the study period. The samples were transported to the laboratory in the dark at 32° F (0° C) for immediate NR activity analysis. Leaf water content was determined on three subsamples by drying the tissue for approximately 24 hours at 176° F (80° C). The dried samples were stored for subsequent determinations of nitrogen and NO_3^- content. Stem xylem pressure potentials were measured with a PMS pressure bomb. Precipitation received during the study period and ambient air temperatures were compiled from a U.S. Weather Bureau station located within 33 feet (10 meters) of the study site. NR activity and NO_3^- content were determined on three subsamples of leaf material from the field samples. Total

leaf nitrogen was determined on three subsamples of a composite sample. To assay in vitro NR activity, leaf material (ca. 0.5 grams fresh weight per sample) was ground cold in a mortar with 5 ml extraction medium and 3 grams washed quartz sand. The grinding medium consisted of 25 mM K_2HPO_4 at pH 7.5, 5 mM EDTA·Na_2, 10 mM 2-mercaptoethanol and 3 percent (W/V) BSA, the last added to stabilize enzyme activity (Schrader and others 1974). After centrifugation at 30 000 g for 15 minutes, the supernatant crude extract was assayed for NR activity within 1 hour. The assay procedure was essentially that of Hageman and Hucklesby (1971), with the zinc acetate/phenazine methosulfate modification of Scholl and others (1974).

Oven dried leaf material was ground to 40-mesh for determination of nitrogen and NO_3^- content. Two tissue samples from each of the subsamples were digested (block digestor) for nitrogen determinations with 20:1 H_2SO_4:H_3PO_4 in the presence of 200:1 K_2SO_4:Se catalyst mixture. Nitrogen content was determined from an aliquot of the diluted digest, using the colorimetric method involving the reaction of ammonium with sodium salicylate, sodium nitroprusside, and sodium hypochlorite with absorption readings at 660 nm (Technicon Industrial Systems, Industrial Method No. 334-74W/B^+, 1977). Nitrogen content was calculated using standard NH_4Cl concentrations carried through the digestion and colorimetric procedure. Nitrate content was determined by the method of Cataldo and others (1975).

RESULTS

Diurnal NO_3^- Levels and NR Activity

Maximum NR activity occurred at solar noon and minimal activity occurred 4.5 h after solar noon (table 1). Leaf NO_3^- levels were highest prior to sunrise. These data suggest a diurnal NR activity rhythm, a pattern consistent with other findings (Bowerman and Goodman 1971; Lewis and others 1982). Diurnal NR activity and residual NO_3^- levels indicate considerable NO_3^- was translocated into the leaf tissue during the photoperiod.

Seasonal NR Activity

Maximum leaf NR activity occurred during the initial sampling date of August 1981 (fig. 1A). At this time, mature fruits were present on the plants sampled, although a large proportion of the fruits had already abscised. NR activity decreased after this initial sampling date to a reasonably stable rate (approximately 6 µmol $NO_2^- \cdot gDW^{-1} \cdot h^{-1}$) that persisted through the winter to early June. Increased NR activity occurred in mid-June and coincided with the onset of reproductive growth and summer rainfall (fig. 1D). This increase in NR activity continued throughout the reproductive growth period (June through November). Mature fruits were abscising

Table 1.--Diurnal in vitro leaf nitrate reductase (NR) activity and NO_3^--N levels within the uppermost, young leaves of *Atriplex canescens* (Pursh) Nutt. growing in situ on September 25 (approximately solar noon) and September 26 (prior to sunrise and approximately 4.5 hours after solar noon), 1981. Values in parentheses represent ± 1 standard error of the means.

	Before sunrise	Solar noon	4.5 hrs past noon
NR activity			
(µmol $NO_2^- \cdot gDW^{-1} \cdot h^{-1}$)	4.71	8.61	2.95
	(1.68)	(2.29)	(1.40)
NO_3^--N			
(mg $NO_3^-N \cdot gDW^{-1}$)	0.94	0.76	0.77
	(0.01)	(0.15)	(0.05)

during the last sampling date of November 3, 1982. The high NR activity found during the initial sampling date in August 1981, was not evident during reproductive growth in 1982. NR activity has been shown to fluctuate in response to leaf water status in several plants (Beevers and Hageman 1980), and in *A. confertifolia* irrigated with various levels of NaCl (Kleinkopf 1975). In the present study, activity of NR and leaf water content (fig. 1C) followed similar seasonal trends and were significantly correlated ($P<0.05$; $r=0.47$). Seasonal xylem water potentials of the terminal portion (4 to 6 inches/10 to 15 cm) of stems bearing leaves representative of those assayed for NR activity were not, however, significantly correlated ($P<0.10$) with leaf NR activity.

Maximum NO_3^- levels (fig. 1A) coincided with minimal NR activity (fig. 1A) and low leaf water content (fig. 1C) during the winter. Similar increases in leaf NO_3^- concentrations have been associated with the inhibition of NR activity by leaf water stress resulting in an accumulation of the NR substrate, NO_3^- (Plaut 1973; Srivastava 1980). Leaf NO_3^- levels and NR activity followed similar trends for the remainder of the study. Precipitation during the latter period (fig. 1D) would tend to enhance root growth, and thus NO_3^- uptake and its translocation to leaves. Similarly, more favorable soil water relations following precipitation would enhance leaf water relations (fig. 1C) for efficient NO_3^- reduction by NR (Kleinkopf and others 1975). Total reduced nitrogen varied between 38 (May 1982) and 25 mg $N \cdot gDW^{-1}$ (November 1982) (fig. 1B).

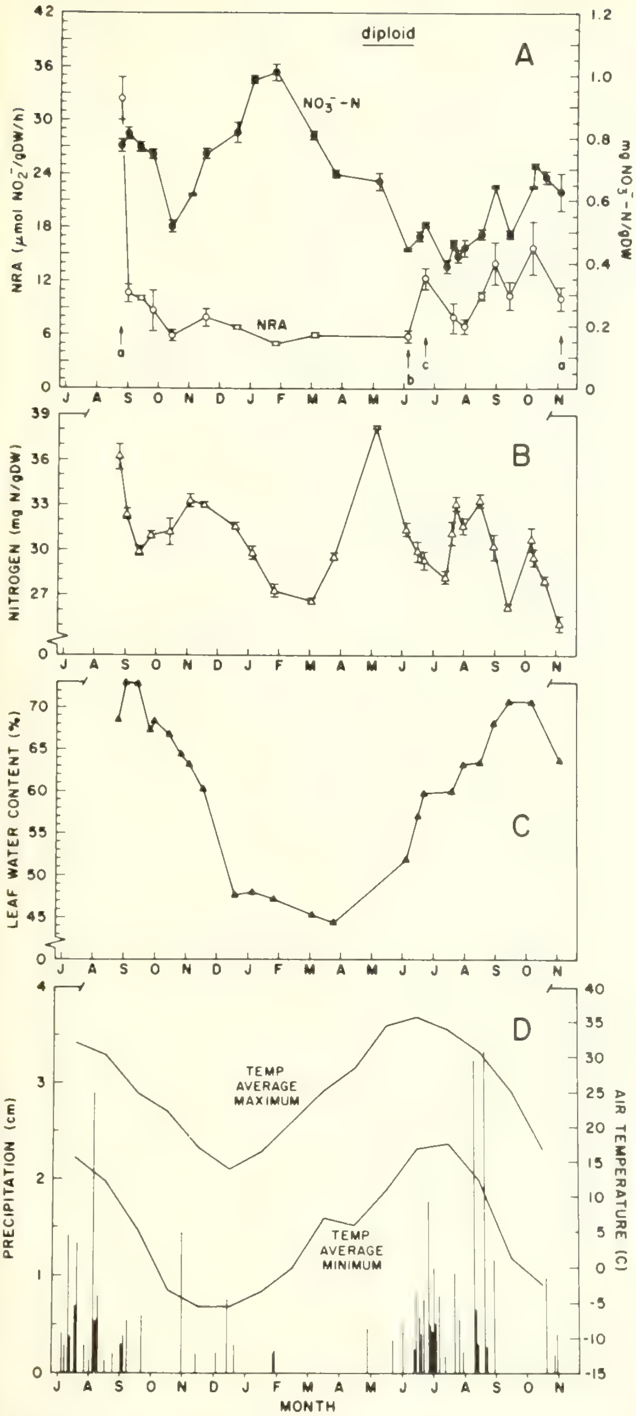

Figure 1.--Seasonal leaf nitrate reductase (NR) activity and leaf NO_3^--N (A), nitrogen (B), and leaf water content (percent) (C) of the diploid genotype of Atriplex canescens (Pursh) Nutt. growing in situ. Vertical bars represent ± 1 standard error of the means. Reproductive growth stages are indicated in A by arrows (a - mature fruit present and some fruit abscission; b - first observation of flowering; c - fruit growth initiated). Monthly ambient average high and low temperatures and precipitation (D) approximately 33 feet (10 meters) from the study site from August 1981 through October 1982.

Leaf N content declined 35 percent during the initial 7-month period when leaf water content and NR activity substantially declined. Thereafter, a discernible seasonal trend in nitrogen levels was not evident.

The potential for thermal adaptation of NR to seasonal fluctuations in ambient temperature (fig. 1D) was determined on leaf samples collected from October 1981 through October 1982 (fig. 2). Maximum NR activity occurred at approximately 86° to 95° F (30° to 35° C) assay temperature, regardless of the sampling date. NR activity at 86° to 95° F (30° and 35° C) differed significantly ($P<0.05$; NR activity at 86° F > 95° F; 30° C > 35° C) only on July 22, 1982. Therefore, the ability of NR to acclimate to seasonal ambient temperature fluctuations was not apparent in the present study.

The thermal stability of NR was determined at 5-minute intervals for 20 minutes at 68°, 86°, and 104° F (20°, 30°, and 40° C) to determine if NR activity was stable throughout the incubation period (15 minutes) during routine assays (fig. 2, insert). NR activity remained fairly constant throughout this 20-minute period at 68° and 86° F (20° and 30° C), but decreased approximately 35 percent at 104° F (40° C). Thus, NR activity depicted in figure 2 at 104° and 113° (40° and 45° C) (and perhaps 95° F (35° C)) probably represents nonstable rates and is a function of the rate of thermal inactivation during the incubation period of routine NR activity assays.

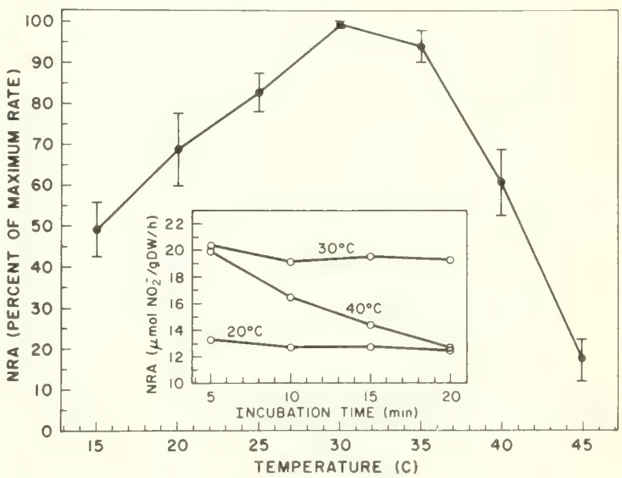

Figure 2.--Nitrate reductase (NR) activity response to temperature 59° to 113° F; 15° to 45° C) for Atriplex canescens (Pursh) Nutt. growing in situ from October 1981 through October 1982. Data from all analyses (10/20/81, 11/3/81, 1/14/82, 3/24/82, 5/6/82, 6/15/82, 7/22/82 and 10/8/82) were combined and are shown. Vertical bars represent 95 percent confidence intervals. Thermal stability of NR activity within the young, uppermost leaves during October 19, 1982, at 68°, 86°, and 104° F (20°, 30°, and 40° C) is shown in the insert.

DISCUSSION

Throughout this study, an attempt was made to collect random, but uniformly young, leaves from the south side and top of plant canopies. Therefore, it would be reasonable to assume that seasonal leaf samples were not representative of a single age group or include sequentially older leaves as the study progressed. The age composition of the leaves present, and hence leaf samples collected, varied throughout the year in response to leaf aging, abscission, and the initiation of new leaf growth. Thus, results of the present study are representative of the youngest, most physiologically active leaves present at any given time, where nitrogen assimilation primarily occurs (Srivastava 1980).

The effect of leaf age was readily demonstrated on August 25, 1981, when the older leaves of plants growing _in situ_ possessed NR activity equivalent to 3 percent of that of younger leaves. Leaf water content of the older leaves was approximately 6 percent less than that of the younger leaves.

Seasonal leaf NR activity of _A. canescens_ growing _in situ_ was significantly correlated ($P<0.10$) with leaf water content, consistent with results from other studies (Huffaker and others 1970; Morilla and others 1973; Tischler and others 1978). On a seasonal basis, stem xylem water potentials were not correlated ($P<0.10$) with NR activity. During periods of low NR activity and leaf water content, NO_3^- accumulated in the leaves. Nitrate accumulation and lower NR activity during water stress have been attributed to a decline in the synthesis of NR (Morilla and others 1973). Shaner and Boyer (1976a, b) demonstrated that NR activity recovery after cessation of water stress was dependent upon protein synthesis and correlated with NO_3^- flux into the leaves rather than the leaf NO_3^- content. Thus, the controlling influence of optimal soil water content on NO_3^- availability and uptake, and the need for favorable leaf water content for efficient NR activity within plants growing _in situ_, is evident from the present study and others.

Reproductive growth during the post-flowering period resulted in substantial NR activity increases in _Phaseolus vulgaris_ L. (Franco and others 1979). In contrast, a continuous decline in both NR activity and NO_3^- uptake occurred during this same period in soybean (_Glycine max_ L.) (Franco 1977; Harper and Hageman 1972). In the present study, reproductive growth by _A. canescens_ appeared to have little or no influence on leaf NR activity since low NR activity coincided with flowering (June 4, 1982). Rather, the enhanced levels of NR activity that occurred during reproductive growth were probably due to rainfall on the study site and new leaf growth. Hence, leaf NR activity coincident with reproductive growth of _A. canescens_ growing _in situ_ appears dependent upon favorable plant and soil water relations. These conditions would enhance soil NO_3^- availability and uptake, its translocation to leaves, and the production of new leaves. The wing-like bracts of the fruits possess the enzyme (2.1 µmol $NO_2^- \cdot gDW^{-1} \cdot h^{-1}$, September 1982) and thus, the primary site of nitrogen reduction for developing seeds may be within these bracts, independent of leaves.

There was no evidence in the present study suggesting that NR of _A. canescens_ growing _in situ_ is capable of thermal adaptation to seasonal ambient temperature fluctuations (fig. 2). Maximum NR activity occurred at assay temperatures of 86° to 95° F (30° to 35° C) throughout the year, though monthly average temperatures varied from a maximum of 97° F (36° C) in July to a minimum of 21° F (-6° C) in January. Harmer and Lee (1981) suggested acclimation of NR appeared evident in two grass species because NR activity increased after transferring the plants from a 68° F (20° C) growth temperature to one of 41° F (5° C) for 1 week. However, lack of pertinent associated data such as assay temperature, tissue NO_3^- levels, and particularly NR activity over a range of temperatures tends to obscure an interpretation concerning the occurrence of acclimation. For example, in the present study, NR activity at an assay temperature of 86° F (30° C) was 4.3 µmol $NO_2^- \cdot gDW^{-1} \cdot h^{-1}$ in October and 9.0 µmol $NO_2^- \cdot gDW^{-1} \cdot h^{-1}$ during November when ambient average daily temperatures were 59° and 48° F (15° and 9° C), respectively. Although higher NR activity occurred in leaves during the colder month of November, acclimation was not evident because maximum NR activity during both months occurred at 86° F (30° C) when assayed at temperatures between 59° and 113° F (15° and 45° C). As a general phenomenon, thermal acclimation of NR would be adaptive for evergreen plants inhabiting environments with large annual fluctuations in ambient temperature. However, there appears little evidence at the present time that NR is capable of such acclimation.

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WINTER NUTRITIVE VALUE OF ACCESSIONS OF FOURWING SALTBUSH

(Atriplex canescens [Pursh] Nutt.) GROWN IN A UNIFORM GARDEN

Bruce L. Welch and Stephen B. Monsen

ABSTRACT: Winter crude protein and in vitro digestibility were determined for the current year's growth of 43 and 31 accessions of fourwing saltbush (Atriplex canescens [Pursh] Nutt.) grown in a uniform garden. The crude protein level varied significantly among the accessions from 6.0 to 14.2 percent. In vitro digestibility also varied significantly among the accessions from 29.1 percent to 46.9 percent. Productivity varied significantly among the accessions from 197 to 1 451 grams per plant. Genetic factors play an important role in determining crude protein level, digestibility, and productivity in fourwing saltbush. Selection and breeding programs can be designed to capitalize on this genetic variation in developing superior cultivars of fourwing saltbush.

INTRODUCTION

Energy producing compounds and protein are nutrients commonly listed as being deficient in the winter diet of mule deer and livestock (Dietz 1965; Halls 1970; Nagy and Wallmo 1972; Welch and McArthur 1979a). Plants that retain significant amounts of green leaves during the winter usually contain higher levels of nutrients than those that shed their leaves (Ensminger and Olentine 1978; Welch 1983; Welch and others 1983a). There is evidence that individual plants and accessions of fourwing saltbush (Atriplex canescens [Pursh] Nutt.) vary in the number of leaves retained during the winter (McArthur and others 1978; McArthur and others 1983). This differential retention of winter leaves among individual plants and accessions of fourwing saltbush is probably associated with differences in winter nutritive value (Welch and others 1983a). Also, McArthur and others (1983) reported significant quality difference among accessions of fourwing saltbush grown in a uniform garden. Welch and Monsen (1981) demonstrated that 43 accessions of fourwing saltbush differed significantly in winter crude protein content. We undertook this study to determine the in vitro digestibility of 31 accessions with the highest crude protein. We also estimated the forage production for 41 of the 43 accessions.

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MATERIALS AND METHODS

A uniform garden was located about 5 miles (8 km) south of Bliss, Gooding County, Idaho. Prior to planting, the garden was cleared of Wyoming big sagebrush, Artemisia tridentata spp. wyomingensis, and associated perennials and annual grasses. Cultural methods were used to control the weeds. The establishment of the fourwing saltbush garden has been described by Welch and Monsen (1981).

From this garden, 43 accessions of fourwing saltbush were selected to evaluate variations in winter in vitro digestibility, crude protein, and production. Table 1 lists the county and state where the seeds for each accession were collected. From each accession, five plants were selected at random for this study.

Current year's growth (leaves and stems) was collected at random throughout the entire crown of the plants during February 1980. Samples were placed in paper bags, transported to the laboratory, and allowed to air dry for 5 days. Then the samples were ground in a Wiley mill, passed through a 1 mm screen, and ovendried at 100° C for 48 hours. Total nitrogen was determined by the Kjeldahl method as outlined by the Association of Official Analytical Chemists (1980). Crude protein was calculated by multiplying the nitrogen content by 6.25 (Association of Official Analytical Chemists 1980). Digestibility was determined by the in vitro method described by Pearson (1970). In vitro digestibility was determined on the 31 accessions (13-43) containing the highest amount of crude protein. Data were expressed on a percent dry matter basis.

In August, 1981, productivity was determined for the same plants used in the digestibility and crude protein portion of this study. Ocular estimates were made of the annual herbage production for individual plants (Pechanec and Pickford 1937).

A completely random analysis of variance ($P > 0.01$) was used to detect significance among the fourwing saltbush accessions. Hartley's

test (P > 0.05) was used to test for significant differences among accessions means for digestibility, crude protein, and production. Where needed, percentages were transformed to arcsin (Snedecor and Cochran 1967).

Table 1.--Location of the seed collecting sites for the 43 accessions of fourwing saltbush (Atriplex canescens) used in this study.

1.	Juab Co., Utah (Jericho)
2.	Kane Co., Utah (Kanab)
3.	Washoe Co., Nevada (Reno Experimental Area)
4.	Emery Co., Utah (Hiawatha)
5.	San Juan Co., Utah (Monticello)
6.	Owyhee Co., Idaho (Reynolds Creek)
7.	Lincoln Co., Nevada (Panaca)
8.	Sanpete Co., Utah (Fayette)
9.	San Juan Co., Utah
10.	Iron Co., Utah (Lund)
11.	Delta Co., Colorado (Delta)
12.	Unknown, Arizona (Little Colorado)
13.	Navajo Co., Arizona (Keams Canyon)
14.	Rio Arriba Co., New Mexico
15.	Millard Co., Utah (Garrison)
16.	Sweetwater Co., Wyoming (Green River)
17.	Rio Arriba Co., New Mexico (Rincon Blanco)
18.	Emery Co., Utah (Huntington)
19.	Juab Co., Utah (Nephi)
20.	Coconino Co., Arizona (Kaibab Nat'l. For.)
21.	Emery Co., Utah (San Rafael Swell)
22.	Juab Co., Utah (Excel Canyon)
23.	Mesa Co., Colorado (Grand Junction)
24.	Garfield Co., Utah (Escalante)
25.	Iron Co., Utah (Cedar City)
26.	Elmore Co., Idaho (Bliss)
27.	Washington Co., Utah (St. George)
28.	Uintah Co., Utah (Manila)
29.	Carbon Co., Utah (Ivy Creek)
30.	Beaver Co., Utah (Milford)
31.	Sanpete Co., Utah (Ephraim)
32.	Wasatch Co., Utah (Timpanogas)
33.	Millard Co., Utah (Desert Range Exp. Stn.)
34.	Washington Co., Utah (Pine Valley)
35.	Gunnison Co., Colorado (Gunnison)
36.	San Juan Co., Utah (Fry Canyon)
37.	Juab Co., Utah (Tintic Valley)
38.	San Juan Co., Utah (Mexican Hat)
39.	Emery Co., Utah (Emery)
40.	Coconino Co., Arizona (Tuba City)
41.	Uintah Co., Utah (Randlett)
42.	Bighorn Co., Montana (Decker)
43.	Washington Co., Utah (Jackson Springs)[1]

[1]This collection is probably a synthetic composed of several accessions including the progenitor of 'Rincon' and native Jackson Springs fourwing saltbush.

RESULTS AND DISCUSSION

Winter crude protein levels of the 43 accessions ranged from 6.0 to 14.2 percent with a mean of 9.6 percent (Welch and Monsen 1981, table 2). Crude protein levels of 215 individual plants ranged from 5.3 to 17.1 percent. Analysis of variance detected significance due to accession. Hartley's test detected that some accessions contained significantly higher levels of winter crude protein than others (table 2). Accessions from Washington County, Utah (Jackson Springs); Bighorn County, Mont. (Decker); and Uintah County, Utah (Randlett) contained the highest amounts of winter crude protein. Accessions from Juab County, Utah (Jericho); Kane County, Utah (Kanab); and Washoe County, Nev. (Reno

Table 2.--Winter crude protein levels among 43 accessions of fourwing saltbush (Atriplex canescens) grown in a uniform garden (from Welch and Monsen 1981). Data expressed as a percent of dry matter and as a coefficient of variation (five replications per accession).

Accession number[1]	Percent crude protein	C.V.[3]
1	[2]6.0[a]	14.0
2	7.1[a]	17.3
3	7.5[ab]	11.4
4	7.6[ab]	16.0
5	7.7[ab]	7.1
6	7.7[ab]	9.9
7	7.8[abc]	16.4
8	7.9[abc]	19.9
9	8.0[abc]	18.5
10	8.0[abc]	24.1
11	8.1[abc]	8.4
12	8.1[abc]	12.3
13	8.2[abcd]	3.4
14	8.3[abcd]	15.9
15	8.3[abcd]	14.2
16	8.6[bcd]	23.5
17	8.7[bcd]	33.9
18	8.9[bcd]	24.1
19	9.0[bcd]	31.5
20	9.1[bcde]	16.3
21	9.2[bcde]	14.7
22	9.2[bcde]	7.2
23	9.3[bcde]	9.9
24	9.3[bcde]	10.4
25	9.5[bcde]	20.8
26	9.6[bcdef]	5.9
27	9.8[bcdef]	29.7
28	9.8[bcdef]	18.7
29	10.0[bcdef]	8.3
30	10.2[bcdef]	28.1
31	10.2[bcdef]	23.7
32	10.4[cdef]	14.2
33	10.6[cdef]	13.9
34	10.9[def]	28.4
35	11.5[efg]	22.8
36	11.7[efgh]	10.3
37	11.9[efgh]	16.7
38	12.0[fgh]	25.5
39	12.2[fgh]	22.7
40	12.9[gh]	27.8
41	13.8[gh]	11.2
42	14.1[gh]	21.5
43	14.2[h]	10.8

[1]For location of accessions, see table 1.
[2]Accessions sharing the same letter superscript are not significantly different at the 95 percent level.
[3]C.V. = Coefficient of variation (five replications per accession).

Experiment Station) contained the least amounts of winter crude protein. There was significant variation among plants within a given accession. This is illustrated in table 2 by the accessional coefficients of variation. The coefficients of variation ranged from 3.4 to 33.9 percent. The mean coefficient of variation was 17.2 percent. For those accessions with a large amount of variation, careful intra-accessional selection could greatly improve their winter crude protein levels.

The mean winter crude protein content of fourwing saltbush, 9.6 percent, compares favorably with the crude protein content of evergreen shrubs such as big sagebrush (Artemisia tridentata), 11.4 percent; black sagebrush (Artemisia nova), 11.7 percent; and curlleaf mountain mahogany (Cercocarpus ledifolius), 10.1 percent (table 3). Fourwing saltbush supplies more crude protein to the consuming animal than deciduous shrubs such as antelope bitterbrush (Purshia tridentata), Saskatoon serviceberry (Amelanchier alnifolia), and Gambel oak (Quercus gambelii) and supplies considerably more crude protein than dormant grass (table 3). In general, evergreen shrubs have a higher winter level of crude protein than deciduous shrubs, and deciduous shrubs have a much higher winter level of crude protein than dormant grasses (Cook 1972; Welch 1981; Welch 1983).

The crude protein requirement for wintering sheep and probably for mule deer is 8.9 percent (National Academy of Sciences 1975). Based on the data in table 2, 26 of the 43 accessions would meet or exceed the crude protein requirement for wintering sheep and deer. The winter crude protein requirement for cattle is 5.9 to 8.8 percent (Maynard and others 1979). It is apparent that certain accessions of fourwing saltbush could be used to increase the amount of crude protein on livestock and wildlife winter ranges (Welch 1983).

The in vitro digestibility of 31 accessions of fourwing saltbush ranged from 29.1 to 46.9 percent of dry matter digested. The mean was 38.3 percent (table 4). The in vitro digestibility of 155 individual plants ranged from 22.3 to 63.4 percent of dry matter digested.

Analysis of variance detected significant effects ($P > .01$) due to accession (table 4). Hartley's test detected that some accessions were more digestible than others($P > .05$). Accessions from Washington County, Utah (Jackson Springs); Coconino County, Ariz. (Tuba City); Bighorn County, Mont. (Decker); and Uinta County, Utah (Randlett) were among the most digestible. These four accessions also contained the highest amounts of winter crude protein. The relationship between crude protein and in vitro digestion was significantly related at a correlation coefficient of 0.88. The coefficient of determination was 0.78. As with crude protein levels, there was significant variation among plants within a given accession.

Table 3.--Winter crude protein content of selected range plants.

Range plant	Crude protein (percent dry matter)	Reference[1]
Black sagebrush	11.7	13
Big sagebrush	11.4	1,2,3,4,6, 8,9,10,13, 16,19
Curlleaf mountain mahogany	10.1	3,7
Fourwing saltbush	9.6	12
Chokecherry	8.7	3,5,11,17
Cliffrose	8.6	5,14
Desert bitterbrush	8.5	3,14
Rocky Mountain juniper	8.4	1
Antelope bitterbrush	7.8	1,3,4,7,8, 9,11,14
True mountain mahogany	7.8	1,5,9
Rubber rabbitbrush	7.8	1,11
Shadscale	7.7	10
Gardner saltbush	7.2	10
Utah juniper	6.6	3,5,7
Saskatoon serviceberry	5.9	3,11
Woods rose	5.8	17,18
Gambel oak	5.3	5,19
Apache-plume	4.8	14
Crested wheatgrass	3.9	11
Native grass	3.6	3
Wildrye	3.2	15
Indian ricegrass	3.0	11,15

[1]Reference:
1 - Dietz and others 1962
2 - Welch and McArthur 1979b
3 - Tueller 1979
4 - Bissell and others 1955
5 - Smith 1957
6 - Smith 1950
7 - Smith 1952
8 - Trout and Thiessen 1973
9 - Medin and Anderson 1979 (data converted to dry matter basis)
10 - National Academy of Sciences 1975
11 - National Academy of Sciences 1958
12 - Welch and Monsen 1981
13 - Sheehy 1975
14 - Welch and others 1983a
15 - National Academy of Sciences 1964
16 - Urness and others 1983
17 - Dietz 1972
18 - Welch and Andrus 1977
19 - Kufeld and others 1981

This is illustrated in table 4 by the accessional coefficients of variation. The coefficients of variation for the 31 accessions ranged from 4.5 to 28.0 percent with a low mean of 13.5 percent. For those accessions with a large amount of variation, careful intra-accessional selection could improve their winter digestibility.

The fourwing saltbush mean winter in vitro digestibility of 38.3 percent compares to 57.0 percent for bud sagebrush, 57.4 percent for big sagebrush, 50.0 percent for Indian ricegrass,

Table 4.--*In vitro* digestibility of winter samples of 31 accessions[1] of fourwing saltbush (*Atriplex canescens*) grown in a uniform garden. Data expressed as percent of digested dry matter and as a coefficient of variation (five replications per accession).

Accession	Percent of digestible dry matter[2]	C.V.[3]
20	29.1^{a}	18.1
14	31.1^{a}	7.9
16	31.8^{ab}	16.5
13	32.1^{ab}	4.5
17	32.5^{ab}	27.1
18	33.7^{abc}	16.8
27	34.0^{abc}	19.1
22	35.0^{abc}	10.6
28	35.5^{abc}	15.4
23	35.7^{abc}	11.7
25	36.0^{abcd}	11.4
21	36.1^{abcd}	4.5
19	36.2^{abcd}	13.7
26	36.3^{abcd}	9.1
30	36.3^{bcd}	15.5
24	36.6^{bcd}	9.2
15	37.0^{bcd}	10.0
34	39.5^{cde}	14.1
29	40.4^{cdef}	8.4
32	40.5^{cdef}	17.0
38	40.6^{cdef}	17.9
36	40.9^{cdef}	13.0
33	41.2^{def}	6.8
37	42.9^{def}	12.6
35	43.4^{ef}	8.0
31	44.4^{ef}	28.0
39	45.3^{ef}	19.3
41	45.3^{ef}	11.5
42	46.2^{ef}	21.0
40	46.2^{ef}	11.1
43	46.9^{f}	10.0

[1]For location of accessions, see table 1.
[2]Accessions sharing the same letter superscript are not significantly different at the 95 percent level.
[3]C.V. = coefficient of variation (five replications per accession).

28.1 percent for Gambel oak, and 25.4 percent for antelope bitterbrush. (For additional range forages and references, see table 5).

The digestibility requirement for winter white-tailed deer and probably mule deer is about 50 percent (Ammann and others 1973). Even the most digestible accession of fourwing saltbush falls short. This points to the need for mixing range plants higher in digestibility, such as big sagebrush and dormant grasses, in with the fourwing saltbush.

The productivity of the accessions of fourwing saltbush ranged from 197 to 1 451 grams per plant (table 6). McArthur and others (1983) have reported similar results. On an individual plant basis, productivity ranged from 45 to 2 000 grams. The mean for all plants was 664

Table 5.--*In vitro* digestibility of winter range forages. Data expressed as a percent of digested dry matter.

Shrub	Dry matter digestibility (percent)	Reference
Big sagebrush	57.4	1,2,3,4,5, 6,11
Bud sagebrush	57.0	8
Sand dropseed grass	53.2	3,8
Black sagebrush	53.1	8
Indian ricegrass	50.0	6,8
Curlleaf mountain mahogany	49.1	1,4
Rosehips (Sweetbrier rose)	49.1	4
Winterfat	44.7	8
Rubber rabbitbrush	44.4	6
Shadscale	43.4	8
Chokecherry	38.8	7,10
Fourwing saltbush	38.3	12
Stansbury cliffrose	37.6	9
Desert bitterbrush	35.8	9
Saskatoon serviceberry	34.6	6
Apache-plume	29.8	9
Gambel oak	28.1	5
Antelope bitterbrush	25.4	1,4,6,9
True mountain mahogany	24.3	1,4

[1]Reference:
1 - Urness and others 1977
2 - Wallmo and others 1977
3 - Sheehy 1975
4 - Welch and Pederson 1981
5 - Kufeld and others 1981
6 - Ward 1971
7 - Uresk and others 1975
8 - Welch and others 1983b
9 - Welch and others 1983a
10 - Dietz 1972
11 - Pederson and Welch 1982
12 - This study

grams. McArthur[1] found productivity of a released variety of fourwing saltbush, 'Rincon', to be 4 400 grams on one site and 2 600 grams on a second site.

Analysis of variance detected significance ($P > .01$) due to accession (table 6). Hartley's test detected that some accessions were more productive than others ($P > .05$). Accessions from Arizona (Little Colorado); Navajo County, Ariz. (Keams Canyon); and Emery County, Utah (Emery) were among the most productive. There was significant variation among plants within an accession. This is illustrated in table 6 by the accessional coefficients of variation. The coefficients of variation for the accessions ranged from 7.4 to 96.3 percent. The mean coefficient of variation was 44.9 percent. Intra-accessional variation is much greater for

[1]McArthur, E. D. Unpublished data on file at the Shrub Sciences Laboratory, Provo, Utah.

productivity than for crude protein (17.2 percent) or in vitro digestibility (13.5 percent). For those accessions with a large amount of variation, careful intra-accessional selection could improve their productivity.

Table 6.--Productivity among 41 accessions[1] of fourwing saltbush (*Atriplex canescens*) grown in a uniform garden.

Accession number	Grams of forage	C.V.[3]
10	197[a]	83.8
42	231[a]	65.5
28	287[a]	96.3
35	367[ab]	81.8
34	401[ab]	37.5
21	405[ab]	38.8
37	415[ab]	53.9
7	424[ab]	40.0
11	428[ab]	40.5
36	432[ab]	45.0
26	476[abc]	55.5
3	493[abc]	44.4
17	504[abc]	43.8
24	515[abc]	28.5
32	523[abc]	47.6
5	524[abc]	36.5
22	577[abcd]	43.0
4	581[abcd]	59.3
15	587[abcd]	70.9
6	596[bcd]	50.5
25	667[bcd]	51.9
9	700[bcde]	27.8
8	730[bcde]	7.4
33	754[bcde]	30.8
38	762[cde]	57.6
40	766[cde]	25.1
20	783[cde]	23.8
14	840[cdef]	32.2
27	842[cdef]	39.2
19	846[cdef]	28.7
2	867[cdef]	46.7
41	918[def]	47.0
30	968[def]	43.2
43	975[ef]	39.2
23	985[ef]	16.0
18	991[ef]	12.7
29	1000[ef]	29.2
39	1069[efg]	74.6
13	1101[fg]	59.5
12	1451[g]	42.1

[1]For location of accessions, see table 1.
[2]Accessions sharing the same letter superscript are not significantly different at the 95 percent level.
[3]C.V. = coefficient of variation (five replications per accession).

It should be noted that the accession of fourwing saltbush from Washington County, Utah (Jackson Springs) contained the highest winter level of crude protein (14.2 percent), was the most digestible, and had a productivity well above the average at 975 grams. It may be possible to increase the productivity of the Jackson Springs fourwing saltbush accession by crossing it with the Little Colorado fourwing accession.

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SEASONAL VARIATION IN CRUDE PROTEIN CONTENT OF KOCHIA PROSTRATA (L.) SCHRAD.

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ABSTRACT: Seasonal crude protein content was determined on composite samples of thirteen accessions of *Kochia prostrata* (perennial summer cypress) grown in a uniform garden. The plants were divided into two stem parts, "upper" and "lower." Mean crude protein content was highest during July (14.4 percent) through November (10.2 percent) for "upper" stem parts. For the "lower" stem parts, highest mean protein content was May (12.8 percent) through July (14.0 percent). Accessional differences were not statistically tested; however, differences among accessions were noted. Best use of *Kochia prostrata* as a forage appears to be on fall ranges.

INTRODUCTION

Kochia prostrata, or perennial summer cypress, is being tested as a potential forage plant for western United States ranges. One accession, P.I. 314929 (U-2), has just gone through the final stages of the Soil Conservation Service release process. It has been named 'Immigrant' forage kochia for commercial production and marketing of seed. Perennial summer cypress is a widely distributed shrub native to the arid and semiarid regions of Central Asia and from Southern Europe and Northern Africa to Manchuria (Moghaddam 1978). Ecotypic variation has been noted, e.g. with its height varying from less than a foot (30 cm) to over 4 feet (120 cm) (Balyan 1972; Francois 1976; Keller and Bleak 1974; McArthur and others 1974). *Kochia prostrata* was first introduced to the United States from the U.S.S.R. during the early 1960's (Keller and Bleak 1974). It is often associated with crested wheatgrass in sandy soil because of its deep rooted nature (to 16.4 ft [5 m]) (Prianshnikov 1966). Limited nutritive studies have been conducted. Davis (1979) reported winter (January and March) crude protein varied from 6.2 to 12.5 percent. He also reported winter carotene varied from 1.3 to 11.1 mg/100 g of dry matter. Welch and Davis[1] reported winter *in vitro* digestibility of *K. prostrata* varied from 20.2 to 38.0 percent of dry matter digested. We undertook this study to determine the seasonal crude protein content of accessions of *Kochia prostrata*.

MATERIALS AND METHODS

Thirteen accessions of *K. prostrata* were selected to study seasonal variation in crude protein content. The accessions were grown in a uniform garden at the Snowfield Station, Ephraim, Utah. Sources of the genetic materials for the accessions used in this study are given in table 1. For each accession, five plants were selected at random to furnish a composite sample. The same plants were sampled throughout the study. A composite sample was needed to ensure tissue enough to last throughout the plants' dormant condition within the study period. Vegetative samples were collected during the first week of the

Table 1.--Plant introduction numbers, U-numbers of the Utah Wildlife Resources (W-82-R), soil types, and location for *Kochia prostrata* accessions used in this study.

P.I. number	U. number	Soil type	Location
330708	U-1	*[1]	Tehran, Iran
314929	U-2	*	Stavropol, USSR
*	U-3	*	Yun Dudar, USSR
356824	U-5	Salty	Actobinsk, USSR
356823	U-6	Sandy	Actobinsk, USSR
586822	U-7	Clay	Ural Mountains, USSR
356821	U-8	Salty	Actobinsk, Aral Sea, USSR
356825	U-9	Clay	Actobinsk, USSR
356826	U-10	Salty	Actobinsk, Ural Mtns., USSR
356819	U-11	Salty	Actobinsk, Aral Sea, USSR
356820	U-12	Sandy	Actobinsk, Aral Sea, USSR
356818	U-13	Clay	Actobinsk, Aral Sea, USSR
356817	U-14	Salty	Actobinsk, Aral Sea, USSR

[1]*=Information not available

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[1]Welch, B. L.; Davis, J. N. *In vitro* digestibility of *Kochia prostrata* (L.) Shrad. Great Basin Naturalist. In press.

following months: December, January, February, March, April, May, July, and November (1980-81). The stems varied from about 24 to 30 inches (61 to 76 cm) in length. During most of the year, K. prostrata plants consist of two types of tissues, which we call "upper" and "lower" (remainder of stem) parts of the stem. The "upper" stem is that part of the stem where seeds are developing (spring and summer) or have shed (fall and winter) leaving a dry, brownish, somewhat erect vegetative stem. The "lower" stem is that part of the stem where green leaves are attached. Both types of tissue were sampled from the selected plants. Samples were oven dried at 212° F (100° C) for 48 hours. Then they were ground with a Wiley mill and passed through a 1-mm screen. Ground samples were stored at -34° F (-35°C) in airtight containers.

We used the Kjeldahl method for determining crude protein content (Association of Official Analytical Chemists 1980). Data were expressed as percent of dry matter. A paired t-test was used to detect differences between "upper" and "lower" stem samples for each month and through the 12-month period. Analysis of variance was used to detect significant differences ($p > 0.05$) among months for "upper" and "lower" stem parts. Accessions were replications. Newmann-Kuels multiple range test was used to detect significant differences among treatment means.

RESULTS AND DISCUSSION

Analysis of variance detected significant differences by months for both the "upper" and "lower" stem parts. For the "upper" stem parts, K. prostrata contained significantly higher crude protein in July and November than in the other months (table 2). Crude protein content for the "lower" stem part was significantly higher in May and July. Davis (1979) showed a similar seasonal pattern. Paired t-tests detected significant crude protein content differences between "upper" and "lower" stem parts. "Lower" stem parts contained significantly more crude protein for the months of December through May. "Upper" stem parts contained significantly more crude protein in November than the "lower" stem parts. During January, February, and March, the mean crude protein for the "upper" stem parts was 5.8 percent and for the "lower" stem parts it was 8.4 percent.

Some accessions appeared to contain more winter crude protein than others (table 3), but because sampling was composite, accessional differences could not be statistically tested. Protein content of the "lower" stem parts by accession ranged from a low of 8.6 percent (U-7) to a high of 11.3 percent (U-3), with a mean of 9.9 percent. Combining the crude protein of "upper" and lower" stem parts, U-3 contained 9.1 percent winter crude protein; U-5 contained 8.6 percent; U-1 and U-2 contained 8.4 percent. U-11 contained the least amount of winter crude protein at 5.9 percent. Of special interest was the high crude protein content of U-1 "upper" stem parts in November (19.5 percent) and December (13.8 percent). Other accessions (U-2, U-3, U-5) had high crude protein content during November (15.1 to 18.1 percent), but substantially lower levels in December (5.5 to 7.1 percent). This high level in November and low level in December (except for U-1) was probably due to seed shedding between November and December. If this is true, energy levels of the "upper" stem parts were also probably high (Ensminger and Olentine 1978).

U-1 (and perhaps U-2, U-3, U-5) has the potential of supplying high levels of crude protein on fall ranges. Perennial summer cypress also has value as early spring forage. We found that early spring growth had crude protein values ranging from 12.1 to 21.8 percent with a mean of 18.0 percent.

Kochia prostrata's usefulness to supply winter crude protein is dependent on the stem part ("upper" or "lower") and accession being eaten. The overall winter crude protein content of the "lower" stem part was higher at 8.4 percent (table 4); however, "lower" stem parts may be covered with snow and thus not be available for animal consumption where snow accumulates deeper than 19.71 inches (50 cm). On an accessional basis, the winter crude protein content of the "upper" stem parts varied from 2.8 to 8.7 percent, and varied from 5.4 to 10.9 percent for "lower" stem parts.

Table 2.--Crude protein content of "upper" and "lower" stems of Kochia prostrata across 7 months. Data expressed as percent of dry matter.

Stem part	Month							
	Dec.	Jan.	Feb.	Mar.	Apr.	May	July	Nov.
Upper	5.9[a] [1]	6.1[a]	6.1[a]	5.2[a]	5.7[a]	5.8[a]	14.4[b]	10.7[b]
Lower	8.2[a]	8.5[a]	8.7[a]	9.8[a]	9.8[a]	12.8[b]	14.0[b]	8.6[a]

[1] Values sharing the same letter superscript are not significantly different at the 95 percent level.

Table 3.--The seasonal crude protein content of "upper" and "lower" stems among accessions of Kochia prostrata. Data expressed as percentage of dry matter.

	Month							
Accession	Dec.	Jan.	Feb.	Mar.	Apr.	May	July	Nov.
U-1-U[1]	13.8	8.5	7.9	7.6	6.2	6.2	14.1	19.5
U-1-L[2]	7.3	8.1	9.5	8.7	8.4	14.6	14.2	9.4
U-2-U	6.9	8.5	7.8	7.3	6.9	6.1	13.7	9.4
U-2-L	10.1	8.7	9.0	8.9	9.1	14.2	13.8	8.9
U-3-U	7.1	8.2	8.7	6.8	8.2	8.0	15.8	17.5
U-3-L	9.4	10.6	10.9	9.3	9.3	15.9	12.6	10.2
U-5-U	5.5	7.3	7.3	8.7	5.0	9.2	15.2	18.1
U-5-L	8.8	9.6	9.1	9.9	8.1	17.3	13.2	10.5
U-6-U	4.8	5.4	6.0	4.9	6.6	5.5	14.6	8.5
U-6-L	6.5	8.1	6.5	7.2	7.3	11.4	13.2	7.3
U-7-U	4.0	4.7	5.4	3.2	4.0	4.7	12.9	4.9
U-7-L	12.4	9.2	9.7	6.8	14.6	10.3	10.7	7.2
U-8-U	4.4	3.8	4.5	3.8	4.7	4.9	15.2	7.1
U-8-L	5.8	7.8	8.7	8.5	11.9	10.2	13.7	7.9
U-9-U	4.2	5.2	4.2	3.7	4.0	4.7	14.3	6.6
U-9-L	6.3	8.2	8.9	9.4	10.1	15.2	13.6	7.7
U-10-U	6.6	7.0	6.4	4.6	4.8	5.4	13.9	11.1
U-10-L	8.3	8.0	8.9	8.6	9.8	11.8	15.1	9.0
U-11-U	4.9	4.4	4.9	2.8	4.7	4.1	14.0	8.0
U-11-L	7.3	8.0	8.0	7.2	8.0	11.8	17.3	8.4
U-12-U	5.6	4.9	4.5	5.3	5.2	5.3	13.6	9.8
U-12-L	9.0	7.9	8.3	7.0	7.9	11.1	14.2	9.0
U-13-U	5.1	7.4	5.1	4.7	7.1	5.6	14.4	4.4
U-13-L	8.6	7.8	8.6	5.7	12.1	11.1	14.8	7.3
U-14-U	5.1	4.3	7.3	4.2	6.1	5.1	15.1	8.3
U-14-L	6.2	5.4	7.0	8.0	11.0	11.0	15.3	8.6
Mean - U	6.0	6.1	6.2	5.2	5.7	5.8	14.4	10.2
Mean - L	8.7	8.3	8.7	8.1	9.8	12.8	14.0	8.6

[1] U="upper" part of stem.
[2] L="lower" part of stem.

Because of position of the most nutritious part, and varying snow depths, the value of *K. prostrata* as a winter forage is difficult to evaluate. Its winter *in vitro* digestion is also low (see footnote 1). The best use of *K. prostrata* as a forage appears to be on fall ranges. (See p. 148 for table 4.)

ACKNOWLEDGMENTS

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Table 4.--Winter crude protein content of selected range plants.

Range plant	Crude protein (percent of dry matter)	Reference
Black sagebrush	11.7	13
Big sagebrush	11.4	1,2,3,4,6,8,9,10,13,16,19
Curlleaf mountain mahogany	10.1	3,7
Fourwing saltbush	9.6	12
Chokecherry	8.7	3,5,11,17
Cliffrose	8.6	5,14
Desert bitterbrush	8.5	3,14
Rocky Mountain juniper	8.4	1
Kochia prostrata-U-2	8.4	This study
Antelope bitterbrush	7.8	1,3,4,7,8,9,11,14
True mountain mahogany	7.8	1,5,9
Rubber rabbitbrush	7.8	1,11
Shadscale	7.7	10
Gardner saltbush	7.2	10
Kochia prostrata	7.1	This study
Utah juniper	6.6	3,5,7
Saskatoon serviceberry	5.9	3,11
Woods rose	5.8	17,18
Gambel oak	5.3	5,19
Apache-plume	4.8	14
Crested wheatgrass	3.9	11
Native grass	3.6	3
Wildrye	3.2	15
Indian ricegrass	3.0	11,15

1 - Dietz and others 1962
2 - Welch and McArthur 1979
3 - Tueller 1979
4 - Bissell and others 1955
5 - Smith 1957
6 - Smith 1950
7 - Smith 1952
8 - Trout and Thiessen 1973
9 - Medin and Anderson 1979 (data converted to dry matter basis)
11 - National Academy of Sciences 1975
12 - National Academy of Sciences 1975
13 - Sheehy 1975
14 - Welch and others 1983
15 - National Academy of Sciences
16 - Urness and others 1983
17 - Dietz 1972
18 - Welch and Andrus 1977
19 - Kufeld and others 1981

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Section 4. Seed Physiology

OVERCOMING SEED DORMANCY IN GARDNER SALTBUSH (ATRIPLEX GARDNERI (MOQ.) D. DIETR.) AS A STRATEGY FOR INCREASING ESTABLISHMENT BY DIRECT SEEDING

R. James Ansley and Rollin H. Abernethy

ABSTRACT: Two seed-related factors, dormancy and seedling vigor, contribute to the lack of success in direct seedings of shrub species, including Gardner saltbush. Alleviation of seed dormancy to varying degrees has been obtained by applying combinations of pregermination seed treatments to Gardner saltbush seeds. Evidence from field studies indicates that seedling vigor plays a key role in successful Gardner saltbush seedling establishment.

INTRODUCTION

Gardner saltbush (Atriplex gardneri (Moq.) D. Dietr.) is a low growing perennial half shrub 8-20 in (20-50 cm) high which occurs in cold desert regions of Montana and Wyoming (Stubbendieck and others 1981). It is particularly adapted to saline, alkaline,and clayey soil conditions, extreme temperatures, high winds, and aridity. On rangeland and disturbed lands, it is a valuable winter forage and serves as a site stabilizer in areas where grasses are not predominant.

Revegetation with Gardner saltbush and related xerophytic shrub species by direct seeding has often been unsuccessful (Bleak and others 1965; McKell 1979; DePuit and Coenenberg 1980). In addition to environmental constraints, two physiological factors, seed dormancy and poor seedling vigor, may be responsible for failures of direct seeding (Malcolm 1972, Van Epps and McKell 1980).

The overall goal of the research reported here was to increase the reliability and effectiveness of direct seeding as a strategy for establishing Gardner saltbush. Research efforts concentrated on manipulating and/or characterizing the two physiological factors, seed dormancy and seedling vigor. If germination could be increased by overcoming dormancy, then pretreating seeds to overcome dormancy prior to planting could potentially increase establishment by direct seeding. Therefore, the first objective of the study was to develop seed pretreatments which would enhance germination, be economical, and be easy to apply. Additionally, germination response to seed pretreatments can provide correlative information about the physiological and ecological nature of dormancy in Gardner saltbush seeds.

The second objective of the study was to observe seedling vigor by determining field emergence of seed to which pretreatments had been applied and comparing that to laboratory germination of similarly pretreated seed. We did not attempt to improve seedling vigor in this study, but we did want to evaluate the relative effects of dormancy and seedling vigor on establishment of this species.

MATERIALS AND METHODS

Seed Procurement

Seeds were collected in August 1980 and 1981 from three distinct regionally isolated populations of Gardner saltbush 9 to 44 mi (15-70 km) west of Rawlins in the Red Desert Basin of south central Wyoming. The three seed populations were 'Knobs', 'Rasmussen', and 'Red Desert', named after the exits on Interstate-80 nearest them. The elevation ranges from 6660 to 6693 ft (2030-2040 m); average annual precipitation is 5.5 to 7.0 in (14 to 18 cm). Average mean monthly temperatures range from 28° to 68° F (-2° to 20° C) with extremes from -38° F (-39° C) in January to 106° F (41° C) in July (Becker and Alyea 1964). Gardner saltbush exists predominantly as a monoculture at each site. Soils are silt loams with moderate to high electrical conductivities and sodium absorption ratios (Ansley 1983).

Seeds were collected by hand stripping. Freshly harvested seeds were spread on a canvas tarp to air dry. Impurities were removed via screening with a 0.19 in^2 (5 mm^2) mesh and with a "Dakota" adjustable plexiglass column blower (Young and others 1978). Seed fill was determined by slicing 15 replicates of 100 utricles with a razor blade.

Seed Pretreatments

To overcome dormancy, seeds were exposed to scarification (Sc), washing (W), cold stratification (St), and dry afterripening (DA) pretreatments. Seeds occupying a volume of 15.25 in^3 (250 cm^3) were scarified for 20 seconds in a

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Forsberg scarifier at 1725 r/min. For washing, seeds occupying a volume of 12.20 in^3 (200 cm^3) were placed in a 20.34 oz (600 ml) beaker, covered with cheesecloth and exposed to continually flowing tap water (43° F (6° C); flow rate of 1.19-1.36 oz (35-40 ml) per sec) for 24 hours. Washed seeds were then air dried 70° F (21° C) for 24 hours to facilitate handling. Cold stratification involved maintaining imbibed seeds on germination blotter at 36° F (2° C) for 3 or 4 weeks. The sequence of application of combination treatments (Sc+W, Sc+St, W+St, and Sc+W+St) is shown in figure 1. To determine effects of DA, seeds were evaluated at various postharvest dates.

Blotter Germination Conditions

Pretreated seeds were germinated in a germinator cycling at 75° F (24° C) for 16 hours of light, and 55° F (13° C) for 8 hours of darkness. Each treatment was replicated six times. Each replication consisted of 100 seeds on one sheet of heavy blotter contained in a 4 by 5 by 1 in (10 by 10 by 2.5 cm) plastic box with a tightly fitting lid, with an initial application of 0.34 oz

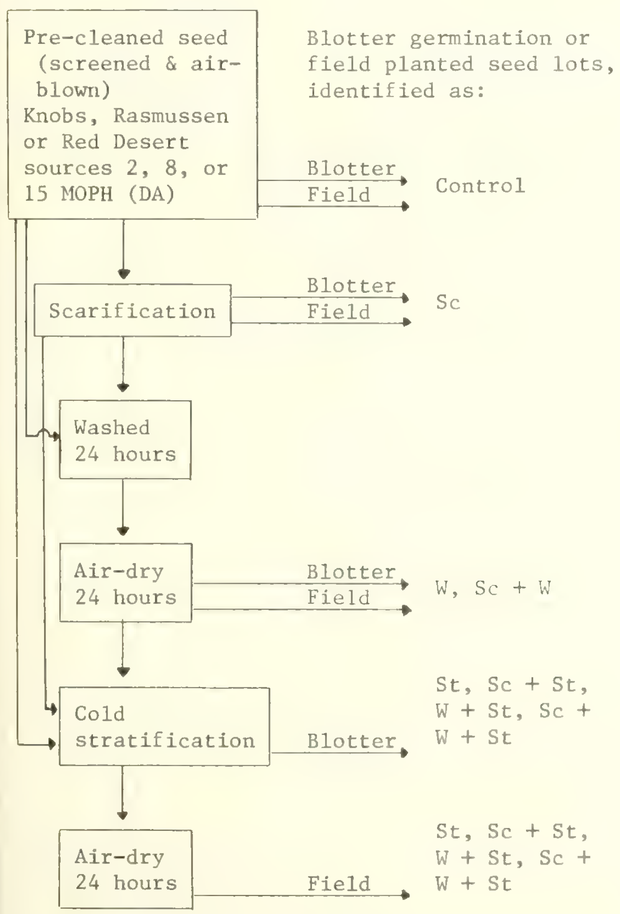

Figure 1.--Seed pretreatment application flowchart.

(10 ml) distilled water. Seeds which were stratified (either as a single treatment or in combination with others) were transferred directly to the germinator while in the hydrated condition following stratification. Other pretreatments were air dried (fig. 1).

Seeds from all three sources were evaluated on germination blotter. Germination, as indicated by 0.6 in (15 mm) radicle extension, was assessed at 3, 5, 10, 15, 25, 35, and 45 days.

The term "germination" in this study refers only to those events preceding and ending with radicle emergence from the testa. "Seedling vigor" refers to postgermination emergence from soil and subsequent establishment. Cotyledon or perisperm reserve utilization is considered a post-germination event and is thus an aspect of seedling vigor (Bewley and Black 1982).

Field Emergence Study

Eight- to ten-month postharvest (MOPH) 'Red Desert' seeds collected in August 1981 were used for the field study. Seeds were pretreated and spring planted at three different sites in Wyoming:

(1) On April 7 and again on April 27, at a topsoiled coal mine reclamation site operated by Bridger Coal Co., 19 mi (30 km) west of Wamsutter;

(2) On April 28, at a topsoiled bentonite mine reclamation site operated by Wyo-Ben, Inc. 7.5 mi (12 km) east of Thermopolis; and

(3) On June 9, at University of Wyoming research plots in Laramie.

Pretreatments (Sc, W, St) were arranged in a completely randomized 2X2X2 factorial. A single row cone seeder with a knife furrow opener was used for seeding. The seeder requires dry seed. Therefore, all seeds which were washed or stratified, or had washing or stratification as the last of a combination of pretreatments, were air dried at 70-75° F (21-24° C) for 16 to 24 hours prior to seeding.

Each treatment replication consisted of 350 seeds (168 filled seeds) planted at 0.4 in (1 cm) depth (Nord and others 1971; Vories 1981) in a single row 21 ft (6.4 m) long. Treatments were replicated four (April 7) and eight (April 27) times at Bridger, eight times at Thermopolis, and five times at Laramie. Replication number was dependent on the size constraints of each site. Seedlings were counted periodically at each site from June to September 1982. Seedlings were considered emerged when the first pair of non-cotyledon leaves were observed.

To observe emergence under dryland conditions, the reclamation sites were not irrigated before or after seeding. Both sites were seeded in April to maximize use of soil moisture accumulated during winter. The Thermopolis site was fenced to exclude sheep and deer which are prevalent in the area. The Bridger site was unfenced. It was assumed mining activity less than 980 ft (300 m) from the research site would preclude large herbivores from grazing on the site. Rodents and other small herbivores as well as weeds were not controlled at either of the reclamation sites.

To observe emergence under conditions which might be considered least-limiting, the Laramie site was seeded in early June to avoid colder early spring soil temperatures. Four-tenths in (1 cm) of water was sprinkler applied every 5 days for the first 30 days following seeding. Moreover, large herbivores, rodents, and weeds were excluded.

Concurrent with the field study, 8 MOPH 'Red Desert' 1981 seeds were similarly pretreated and laboratory blotter germinated. Effects of 24 hours air drying (70° F/21° C) following stratification on blotter germination were observed to simulate pretreatment conditions encountered prior to planting during the field study.

Data Analysis

Total cumulative germination (based on percent of filled seed) and germination rate data were obtained in the laboratory tests. Germination rates were evaluated by calculating the mean time in days taken for nondormant viable seeds to germinate, as discussed by Ellis and Roberts (1978). The mean germination time (MGT) was calculated as follows:

$$MGT = \frac{\Sigma(Dn)}{\Sigma n}$$

where D is the number of days from the beginning of the germination assay and n is the number of seeds germinating on day D. The mean germination time determined by this equation is corrected for differences in final germination percentage.

Field emergence was based on the total seedling counts taken in September 1982 and expressed as a percent of filled seed. Data from laboratory and field studies were subjected to analysis of variance procedures. The LSD and Duncan's Multiple Range Test ($P < 0.05$) were used for mean comparison.

RESULTS AND DISCUSSION

Pretreatment Effects on Laboratory Germination

Blotter germination of 2 and 15 months postharvest (MOPH) 'Knobs' 1980 seed is shown in figure 2. Seed fill of this population was determined to be 60 percent. In 2 MOPH seed, stratification (St), and washing + stratification (W+St) enhanced germination in nonscarified seeds. In scarified seeds, W+St was effective but St alone was not. Washing alone was not effective in intact or scarified seeds. Washing + St in scarified seed yielded the greatest germination, but this was still only 50 percent of filled seeds. Viability tests from a previous experiment determined that in each of the Gardner saltbush seed populations studied, 85 to 95 percent of the filled seeds were viable (Ansley 1983). Thus, no pretreatment completely removed dormancy at 2 MOPH.

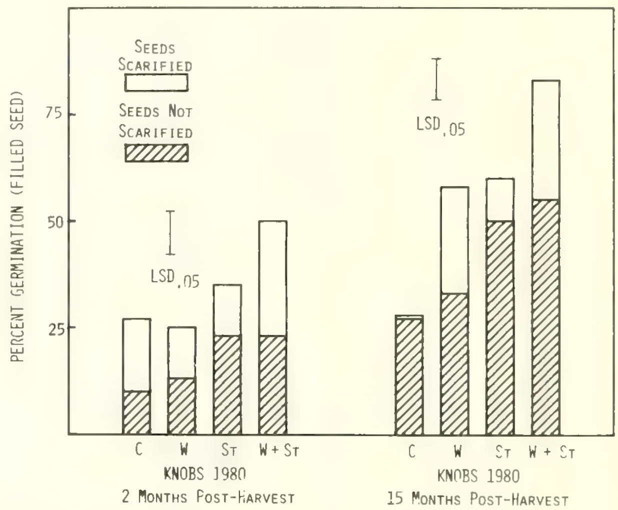

Figure 2.--Effects of 24 hours washing (W), 4 weeks stratification (St), and dry afterripening on blotter germination of scarified and intact 'Knobs' 1980 Gardner saltbush seeds.

Germination was greater in 15 MOPH than 2 MOPH 'Knobs' 1980 seed for all treatments except the scarified control (fig. 2). These responses indicate a dry afterripening (DA) effect. Washing was effective in scarified 15 MOPH seed but was not effective in intact seeds. Physiologically, this may indicate that embryo rather than exterior germination inhibiting substances were leached out to overcome dormancy. Stratification enhanced germination nearly equally in both scarified and intact 15 MOPH seeds. This suggests that effects of St were independent of the coat and, therefore, may have been operating on the embryo. Washing + St of scarified seed yielded the greatest germination with almost a complete removal of dormancy.

In addition to embryo dormancy, the 'Knobs' 1980 source may have some seed coat-imposed dormancy. It is well documented that bracteoles and/or seed coats in many *Atriplex* spp. contain salts and/or other compounds which inhibit germination (Beadle 1952, Cornelius and Hylton 1969, Osmond and others 1980). While leaching of nonscarified

seed did not enhance germination of the 'Knobs' 1980 seed source at either postharvest date, scarification alone increased germination significantly in 2 MOPH seed (fig. 2). However, this effect was not seen in 15 MOPH seed of the 'Knobs' 1980 source. This suggests that DA may induce a release from whatever coat-imposed dormancy exists in the early postharvest stages of Gardner saltbush seeds.

Similar trends in response to Sc, W, and St pretreatments were seen with 'Knobs' seed collected the following year (1981) and on seed collected in 1980 from the Rasmussen source, which is about 31 mi (50 km) west of the Knobs site (fig. 3). Both of these seed populations were 15 MOPH

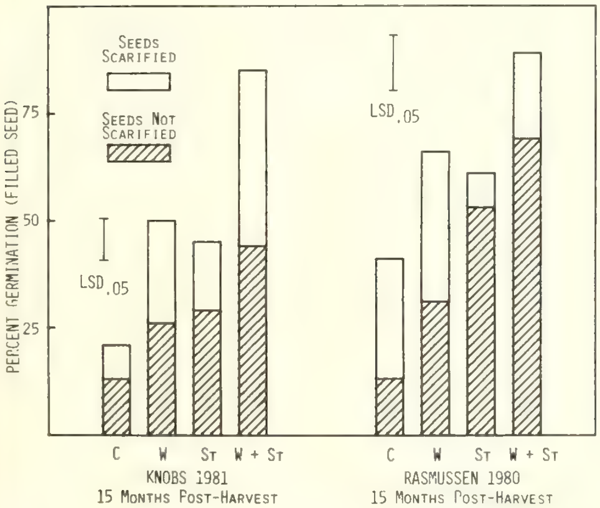

Figure 3.--Effects of 24 hours washing (W) and 4 weeks stratification (St) on blotter germination of scarified and intact 'Knobs' 1981 and 'Rasmussen' 1980 seeds at 15 months postharvest.

at the time of pretreatment application and can be compared directly to 15 MOPH 'Knobs' 1980 results in figure 1. Sc+W+St yielded the greatest germination in seeds from all three sources. Interestingly, response of 'Knobs' seed to St as a single treatment was significantly less relative to other pretreatments in 1981 seed than 1980 seed. 'Rasmussen' showed a much greater sensitivity to scarification than both 'Knobs' 1980 and 1981 seed. Moreover, effects of W on intact seeds were significant in 'Rasmussen' but not in 'Knobs' (fig. 2 and 3). This suggests that 'Rasmussen' seed has a greater degree of coat-imposed dormancy than 'Knobs' seed. Thus, seed source may affect both type of dormancy and dormancy alleviation requirements in Gardner saltbush. This response could be related to the environment of the parent plants during seed maturation, to the genotype of the parent plants, or both. This has yet to be resolved.

Seed pretreatments markedly affected germination rates as well as total germination in all three seed populations. The mean times to germination (MGT) shown in table 1 generally decrease in the order the pretreatments are listed. For all seed sources the shortest MGT (highest germination rate) was obtained by the combination of Sc+W+St. The longest MGT was dependent on source. Stratification was the single pretreatment having the greatest effect on germination rate, and stratification in combination with other pretreatments generally reduced the MGT.

The standard errors for MGT's included in table 1 indicate that as the MGT was reduced by pretreatments the uniformity of germination over time within a pretreatment was increased. This is the response sought for agronomic crops, and it may have implications for the land reclamation specialist seeding Gardner saltbush. Using various combinations of the pretreatments described in this study, it was possible to adjust, to some degree, the level of seed dormancy remaining

Table 1.--Mean time to germination (MGT) in days for Gardner saltbush seed sources following application of pregermination treatments.

	Seed source			
Pretreatment	Knobs 1980 2 MOPH	Knobs 1980 15 MOPH	Knobs 1981 15 MOPH	Rasmussen 1980 15 MOPH
Control	[1]18.1 (3.4)	14.6 (1.0)	17.9 (2.5)	26.6 (1.7)
Washed	24.2 (2.9)	14.0 (1.5)	14.0 (1.3)	22.0 (1.5)
Scarified	13.6 (1.9)	13.0 (1.2)	16.3 (1.1)	30.1 (2.7)
Scarified + washed	16.4 (0.7)	10.5 (0.4)	12.7 (0.6)	16.8 (0.8)
Scarified + stratified	11.0 (0.5)	4.8 (0.5)	9.5 (0.9)	9.9 (0.8)
Washed + stratified	13.5 (1.2)	4.2 (0.3)	8.0 (0.7)	9.2 (0.6)
Stratified	12.3 (0.8)	4.1 (0.3)	10.9 (0.4)	8.1 (0.7)
Scarified + washed + stratified	9.9 (1.0)	3.9 (0.1)	6.4 (1.0)	7.7 (0.6)

[1]Mean time in days and (standard error).

in a seed source and the rate and uniformity of germination. The implication of this is that when the reclamation site is to be irrigated or is likely to receive ample precipitation and the site is otherwise favorable, it may be advantageous to use seed pretreated to achieve rapid and uniform germination. Under less favorable and/or predictable seeding conditions, it may well be advantageous to use pretreatments allowing a portion of the seed to remain dormant.

Field Emergence

Eight MOPH 'Red Desert' 1981 seeds were used for all field emergence studies. Seeds were stratified 3 rather than 4 weeks prior to field planting because it was determined that a significant number of dry afterripened 'Knobs' and 'Rasmussen' seeds had germinated after 4 weeks of stratification. Seeds with radicles protruding would not survive the planting operation. Limiting the stratification treatment period to 3 weeks did reduce the blotter germination percentage somewhat relative to that obtained in the other seed sources which were stratified for 4 weeks (fig. 2 to 4).

It was determined that air drying of stratified seeds did not adversely affect the enhancement effect of St on blotter germination, except for a slight decline in scarified seeds treated with W+St (fig. 4).

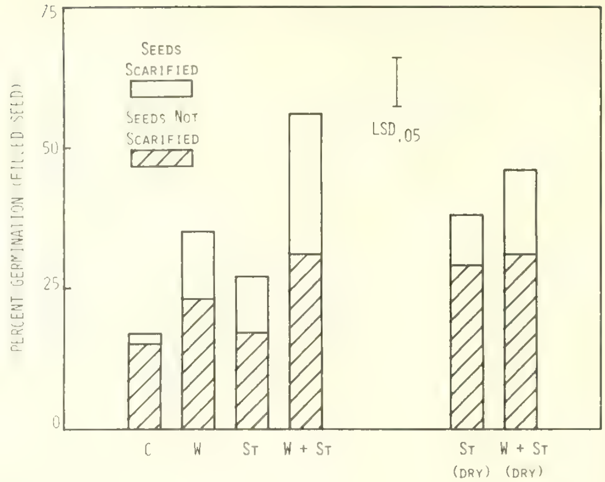

Figure 4.--Effects of 24 hours washing (W) and 3 weeks stratification (St) without and with a 24 hour air-drying (Dry) period prior to assay of blotter germination of scarified and intact 8-month postharvest 'Red Desert' 1981 Gardner saltbush seeds.

For all seed pretreatments blotter germination was substantially higher than field emergence, including the Laramie site where conditions were considered least limiting (fig. 4 and table 2).

Table 2.--Effects of seed pretreatments on field emergence of 8 month postharvest 'Red Desert' 1981 Gardner saltbush seeds at two dryland reclamation sites (Bridger and Thermopolis) and one irrigated site (Laramie).

	Percent emergence (filled seed)[1]			
	Bridger dryland		Thermopolis dryland	Laramie irrigated
Pretreatment[2]	April 7	April 27	April 28	June 9
1. Control	0 a	1 a	1.2 d	1.0 d
2. Scarified	1 a	1 a	2.9 bcd	2.0 cd
3. Washed	1 a	0 a	1.6 cd	1.4 d
4. Scarified + washed	1 a	1 a	2.3 cd	3.8 cd
5. Stratified	1 a	0 a	3.1 bc	9.2 b
6. Scarified + stratified	1 a	1 a	5.2 a	16.7 a
7. Washed + stratified	1 a	1 a	3.0 bcd	8.6 b
8. Scarified + washed + stratified	1 a	1 a	4.6 ab	6.0 bc

[1]Each mean based on percent emergence of 168 filled seeds (out of 350 total seeds). Emergence data were obtained 11 to 17 weeks after seeding at all sites.
[2]Treatments: Control = untreated seed, W = 24 hours washing, St = 3 weeks stratification, Sc = scarification.
[3]Means within each column having similar letters are not significantly different at P $\leq$ 0.05 according to Duncan's New Multiple Range Test.

This suggests that Gardner saltbush seedling vigor is poor and may inhibit establishment from direct seeding in the spring as much as seed dormancy, if not more.

When dormancy was combined with poor seedling vigor, very little establishment occurred at any site. When dormancy was removed, establishment was increased at Thermopolis and Laramie. The number of seedlings that emerged at Bridger was so low that conclusions regarding effects of pretreatments on field emergence were tenuous. At Laramie Sc+St yielded the greatest emergence (table 2). This differs from blotter germination results which indicated that Sc+W+St was the most effective pretreatment.

Washing was shown in a previous study (Ansley 1983) to remove over 11 percent of the ovendry material in both scarified and intact Gardner saltbush seeds. Apparently, loss of this material, combined with the dry weight loss due to scarification (18 percent), did not inhibit blotter germination but may have adversely affected seedling vigor and subsequent field emergence.

CONCLUSIONS

Ecologically, treatments were selected for this study which reflected conditions in the natural environment which might overcome seed dormancy in Gardner saltbush. In the cold, windy, and arid environment of the Red Desert Basin, seeds could potentially be exposed to all the pretreatments (scarification, dry afterripening, washing, stratification) artificially created in this study. Moreover, species which have evolved in harsh climates often have complex seed dormancies which may involve the interaction of several environmental factors to break dormancy. This appears to be so for Gardner saltbush.

In summary, Sc, W, St,and DA individually increased laboratory blotter germination of several populations of Gardner saltbush seeds to varying degrees. However, complete dormancy removal did not occur until the seed was exposed to all four pretreatments.

The pretreatments were economical and easy to apply to the seeds. Pretreating seeds to overcome dormancy served as an effective strategy for increasing establishment of Gardner saltbush via direct seeding on two of three sites evaluated. The combination of Sc+St yielded the greatest field emergence. Washing, while promoting blotter germination, appeared to inhibit field emergence of scarified and stratified (Sc+St) seeds. These results suggest that care must be exercised in using laboratory germination results to predict the potential field performance of a seed lot. Laboratory germination and field establishment responses to specific treatments may not always be identical.

Seedling vigor was quite poor in this species and substantially reduced establishment success even when growing conditions were least-limiting and seed dormancy was alleviated.

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ECOLOGY OF SEED GERMINATION IN REPRESENTATIVE CHENOPODIACEAE

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ABSTRACT: Seeds of species of the Chenopodiaceae exhibit a variety of germination and dormancy mechanisms. In certain species, germination can be very rapid following the rupture of the pericarp (testa) during imbibition of water. Persistent and sometimes indurate fruiting bracts sometimes induce dormancy by reducing osmotic potentials through accumulation of soluble salts, by limiting transfer of moisture and/or gases to the embryo, or through chemical inhibitors. The production by the same plant of polymorphic forms of seed, often having dramatically different germination characteristics, is a major characteristic of chenopods.

INTRODUCTION

The family Chenopodiaceae includes about 100 genera and possibly 1,400 species (Lawrence 1959). Interest in the ecology of germination of this family is high, because it includes: (a) cosmopolitan weeds, (b) shrubs native to western North America that are desirable species for revegetation of disturbed wildlands, and (c) species whose natural habitat includes seedbeds with osmotic potentials lowered by accumulations of soluble salts and possibly toxic specific ions. This paper highlights the germination ecology of representative native chenopod shrubs, especially those that are species of Atriplex. Unfortunately, with a few exceptions, there is much more germination literature devoted to weedy chenopods and extreme halophytes than to shrubs suitable for revegetation of wildlands. Individual scientists and managers interested in the seedbed ecology of shrubby species of Atriplex have a considerable amount of related germination literature that can be extrapolated to these species. Little specific information exists.

Morphology of Pistillate Fruits

The fruit of the chenopod is usually a one-seeded, thin-walled utricle. The walls of the utricle can become quite complex. In the case of the Atriplex species, more or less foliaceous bracts that surround the pistillate flowers become enlarged and even inflated. These bracts, in some instances, are deposition sites for soluble salts separated by the metabolic processes of the plants, which help to maintain osmotic equilibrium. These accumulated salts can be a major factor in influencing germination characteristics of chenopod seeds.

The members of the Chenopodiaceae family are often classified by characteristics of the embryo. The embryo can be tightly spirally coiled as in the case of Halogeton or Salsola or annular (ring-shaped or conduplicate) as in the case of Atriplex species. There are exceptions to all generalizations, and in some chenopods such as Beta the ovary is sunk into the succulent base of the calyx which at maturity forms an irregular, indurate ball.

GERMINATION OF WIDELY DISTRIBUTED ANNUAL CHENOPODS

Chenopodium album L.

This comopolitan weed is a pest in so many agricultural situations that its germination ecology has attracted considerable attention. Any review of the literature on germination of C. album seeds will produce many apparent conflicts. Seeds are light sensitive in an apparent phytochrome relationship (Cumming 1963). Seeds require nitrate or nitrate and chilling for germination (Henson 1970). Germination of C. album seeds can be enhanced by removing the enclosing fruit coat (Chu and others 1978). Williams and Harper (1965) determined that seeds of C. album are polymorphic. The seeds vary in size, color, and surface texture, even in samples from single plants. Three distinct germination responses to cold and nitrate were observed by Williams and Harper (1965). Brown seeds germinate quickly as soon as they are provided with water, even at temperatures as low as 32°F (0°C). Black-reticulate seed dormancy is broken by nitrate, but not by chilling. Black-smooth seed dormancy is broken by nitrate, but is partly replaceable by chilling. The three categories of seed, which may be obtained from one parent, may differ as much in requirements for germination as many species differ from each other.

The seed polymorphism present in C. album is phenotypic. The proportions of the polymorphic categories are not greatly influenced by treatments such as nitrogen fertilization although these greatly modify growth, life cycle, and reproductive output of the species. Williams and Harper (1965) determined that brown seeds, the highly germinable form, are usually the first to mature. Cumming (1959) presents evidence that the production of brown seed by C. album plants may be controlled by photoperiod.

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Chenopodium bonus-henricus L.

The germination of seeds of this species has been widely investigated because of the rather unique characteristics of the seeds. The excised embryos of C. bonus-henricus will germinate when given proper incubation. The fruit coat is thought to contain polyphenol compounds that interfere with oxygen transfer to the embryo (Dorne 1981). Seeds from plants grown at higher elevations exhibit greater inhibition of germination. This is contrary to the phenotypic forms of dormancy in C. album, which occur more or less independently of maternal environmental stimuli, except for day length.

The light requirement for germination of C. bonus-henricus seeds can be substituted for by prechilling (Khan and Karson 1981). This light requirement can be reinstated by prolonged, dark imbibition in low osmotic potential solutions. However, prolonged exposure to radiation of chilled seeds under these conditions prevents dormancy and hastens subsequent germination in light or in darkness (Khan and Karson 1980).

Halogeton glomeratus C.A. Mey

Halogeton glomeratus was accidentally introduced to the salt-desert and lower Artemisia rangelands of western North America. One of the first observations of seed ecology of H. glomeratus was the discovery of black and brown seeds (Tisdale and Zappettini 1953). Black seeds were found to be highly germinable immediately after seed cast while brown seeds were almost entirely dormant in laboratory trials.

Black seeds of H. glomeratus placed on moist filter paper absorb water so rapidly that the ovary wall may rupture and expel the embryo within an hour (Williams 1960). The embryos of black seeds uncoil at once and frequently can be planted within 9 to 10 hours. The embryos of brown seeds only swell slightly when placed on moist filter paper and appear unable to penetrate the protective ovary walls. Excised embryos from brown seeds rarely uncoil within 48 hours. When they uncoil, a green pigment appears in the cotyledons. The embryos of black seeds contain chlorophyll before emergence.

Williams (1960) discovered that in black seeds of H. glomeratus the major portion of resources is stored as sucrose, while storage in brown seeds is starch. Williams also showed that production of the dormant brown seeds is controlled by photoperiod. The brown or dormant form of H. glomeratus seeds is produced first, under long-day photoperiods. The germinable or black seed is produced later, under shorter photoperiods. Late germinating and flowering plants produce only black seeds.

Salsola iberica Sennen and Pau and S. paulsenii Litv.

Salsola iberica and S. paulsenii are alien species widely distributed on Intermountain rangelands in disturbed areas. The plant morphology of both species can be highly variable in terms of size, shape, and color. Despite these observed differences, seed polymorphism does not appear to be prevalent.

Salsola iberica produces a large number of seeds with spirally coiled embryos in a very thin, papery fruit. The fruits are tightly held in axillary bracts and often released only when the plants break off at the soil surface and are tumbled by the wind (Evans and Young 1982). Salsola is not highly competitive with other annuals. A well-developed dispersal system and superabundant seed production help to ensure that some seeds reach freshly disturbed areas.

Seedlings of Salsola in western North America are not particularly frost tolerant. Germination is severely restricted in the fall by temperature-related afterripening requirements (Evans and Young 1982). Gradually over the winter these requirements break down; by late spring the seeds of these species germinate at virtually any seedbed temperature from 28° to 113°F (-2° to 45°C) including diurnal fluctuations of these extreme temperatures. Germination response is controlled internally and is relatively free of external stimuli.

Although the two species of Salsola have similar germination requirements, the afterripening requirements for seeds of S. paulsenii are slightly less restrictive, imparting an apparent competitive advantage in desert situations (Evans and Young 1982).

Atriplex patula ssp. hastata (L.) Hall and Clem.

Seeds of this species do not require light for germination but light enhances germination (Young and others 1981). With light during incubation, germination at optimum temperatures averages 96 percent.

Although seed dimorphism is not readily apparent, different size seeds produce markedly different rates of seedling growth (Baker 1972).

GERMINATION OF SEEDS OF SEMIWOODY CHENOPODS

This is a rather artificial grouping that can be further qualified by limiting it to species that generally occur in almost pure stands over limited areas. These chenopods also happen to be highly desirable browse species. This category includes selected species in the genera Kochia, Ceratoides, and a restricted section of Atriplex. The seeds of these species appear to have highest germination at or very near the surface of seedbeds. The storage life of these seeds is variable and can be quite short.

Ceratoides lanata (Pursh) J.T. Howell

H. W. Springfield spent several years studying the seed ecology of C. lanata. He concluded that for optimum germination a period of afterripening was required (Springfield 1968). Germination of C. lanata seeds was influenced by seedbed temperature and moisture stress (Springfield 1968). Optimum germination occurred at relatively warm incubation temperatures of 77° to 80°F (25° to 27°C) and exceeded 90 percent germination over a wide range of temperatures 50° to 80°F (10° to 27°C) (Springfield 1972b). Springfield (1972) did not find the wide range of polymorphic forms that characterize some of the annual chenopods, but he did determine a wide size range in the seeds of C. lanata and that large seeds had higher germination percentages.

When the germination rates of different collections of C. lanata seeds are compared in relation to temperature or moisture stress, considerable ecotypic variability is apparent (Workman and West 1967; Clark and West 1971). This ecotypic variability has probably contributed to conflicting reports on seed germination of this species and maybe to the variable results obtained in attempts to revegetate rangelands with C. lanata.

Kochia prostrata (L.) Schrad.

This species is native to central Asia and eastern Europe where it is a highly variable, but often valuable,forage plant. It has been imported to the Intermountain area for use in revegetation of range sites including degraded Ceratoides lanata and Kochia americana Wats. communities.

The seeds of K. prostrata uncoil very rapidly at a wide range of temperatures, but true growth, as indicated by raising the hypocotyl arch, occurs in a much more restricted temperature range (Young and others 1981).

Major problems with the use of K. prostrata in revegetation of grazing lands in central Asia have been the short half-life of the seeds in storage and the lack of frost tolerance by seedlings (Nechaeva and others 1977). The storage of small lots of seeds of K. prostrata has not been a problem in the United States (Young and others 1981). (See Jorgensen and Davis, this proceedings, for techniques to handle large volumes of K. prostrata seed.)

Atriplex nuttallii Wats.

This is an extremely diverse phylogenetic group which, depending on the authority, can include the taxa A. gardneri (Moq.) and A. cuneata A. Nels. (See R. J. Ansley and R. H. Abernethy, this proceedings, for germination ecology of A. gardneri). Not only are the members of this group morphologically diverse, but they also occupy a wide variety of environments especially in relation to the soluble salt content of soils (Goodman 1973).

The common threads that more or less characterize this group of semiwoody chenopods appear to be: (a) a great deal of variability, attributed to genotypic rather than phenotypic sources; (b) a high degree of phenotypic polymorphism in seeds; (c) very rapid germination under ideal situations; (d) poor emergence from burial in seedbeds, with surface seeding the most desirable; and (e) short and highly variable seed storage half-life.

GERMINATION OF WOODY SPECIES OF CHENOPODS

The University of California was experimenting with establishing species of Atriplex on grazing land by seeding in 1882 (Jaffa 1899). The Australians have a long history of research on the germination of Atriplex species, highlighted by the classic paper of Beadle (1952). For most of the woody species of chenopods, the embryo is usually borne in fruit that may include complex bracts.

Beadle (1952) described how the seeds of some of the major species of Atriplex in Australia were shed from the plant enclosed in bracteoles. These bracteoles persisted for variable lengths of times until they decayed or were removed by abrasion. For some species, the bracteoles persisted until long after the seeds had lost their viability. When enclosed in the bracts, the seeds germinate only after relatively long periods of moist incubation. Beadle, as had Wood in 1925, attributed this retardation to high concentrations of chloride ions in the fruiting structure.

Beadle (1952) also determined that the seeds of some species of Atriplex did not readily imbibe water. Seeds in populations that had hard seed coats or impermeable testa were highly variable in their ability to imbibe water.

Atriplex canescens (Pursh) Nutt.

The germination of this species has been extensively studied by H. W. Springfield (1970). Maximum germination occurred at moderate incubation temperatures, from 55° to 75°F (13° to 24°C). A. canescens seeds did not respond to the presence or absence of light during incubation. Removal of most of the persistent bracts with a hammer mill speeded up germination, but did not markedly increase 28-day germination levels.

Springfield (1970) found a great deal of variability in the seed coat of A. canescens within and among collections. The seeds of some sources exhibited increased germination with scarification while seeds of other sources showed a marked decrease in germination when scarified.

Eamor Nord also spent considerable time studying the germination and seedbed ecology of A. canescens. He believed there was a saponin-like substance in the bracts that inhibited germination (Nord and VanAtta 1960). Twitchell (1955) enhanced the germination of A. canescens seeds by soaking, but attributed the enhancement to the removal of chlorine.

Despite the assumption that the bracts of A. canescens seeds contained germination inhibitors, Nord also experimented with scarification (Nord and VanAtta 1957). The results of these studies were rather inconclusive.

The much lower germination of filled seeds in tetraploid A. canescens than in diploid plants of A. canescens exemplifies genetic control of dormancy systems (Stutz and others 1976).

Graves and others (1974) found that mechanical scarification of A. canescens was the only treatment that markedly increased 7-day germination rates. It only slightly enhanced the 14-day germination level over the fairly high germination level of the control seeds. Both Graves and others (1974) and Springfield (1970) determined that hot water soaking completely inhibited the germination of A. canescens seeds.

Atriplex polycarpa (Torr.) Wats.

The seeds of A. polycarpa have reduced germination when incubated in the presence of leachate from the utricle (Chatterton 1970; Cornelius and Hylton 1969; Askham and Cornelius 1971). Light is not required for germination of seeds. Graves and others (1974) found that seed size of A. polycarpa markedly influenced germination; large utricles germinated significantly ($P = 0.05$) better than smaller sizes. This size difference could be an influence of the maternal environment or it could be a phenotypic or genotypic expression of polymorphism. Considering the salt-affected soils where many species of Atriplex are found naturally, specific ion toxicity must play a role in the germination ecology of many species (Chatterton and McKell 1969a&b).

Atriplex semibaccata R. Br.

This native to Australia is naturalized in California and southern Nevada. The seeds of A. semibaccata are quite germinable without pretreatment (Young and others 1981). Germination is enhanced by presoaking and wringing the soak water from the fruits. Seeds do not require light for germination.

Atriplex lentiformis (Torr.) Wats.

The seeds of this North American native are quite germinable without pretreatment. A. lentiformis is similar in germination response to A. semibaccata. Light apparently does not play a role in germination. Presoaking does enhance germination (Young and others 1981).

Atriplex confertifolia (Torr. and Frem.) Wats.

The seeds of this landscape-characterizing species of the Intermountain area are generally highly dormant. Considering the rapid evolution of this group in the pluvial lake environment (Stutz 1978), it would appear reasonable that a great deal of ecotypic variability would occur in germination ecology. Overriding dormancy has precluded discovery of appreciable information on the germination of seeds of A. confertifolia. (See D. C. Warren, this proceedings, for a more comprehensive study.) Prolonged outdoor stratification will produce erratic germination.[1]

Atriplex dimorphostegia Kar. et Kir.

Germination of the dimorphic forms of flat and humped seeds of A. dimorphostegia was promoted by short-duration radiation and inhibited by continuous radiation from the same white light source. Germination level was low when in total darkness (Koller 1970). This dual action of light produced an apparent short-day photoperiodic response. Progressive increases in the daily photoperiod caused progressive decreases in germination rate and percentage. The humped seeds were more sensitive to light inhibition (Keller 1957).

Atriplex repanda Phil.

A. repanda is a valuable browse species in the arid portions of Chile (Lailhacar-Kind and Laude 1975). Revegetation with this species has been limited by seed dormancy. Dormancy is apparently imposed by the persistent bracts and a layer that Lailhacar-Kind and Laude (1975) identified as the testa. The bracts are so indurate that mechanical scarification often damages the embryo.

Fernandez, Myrma, and Johnston (Fernandez and Myrma 1978; Johnston and Fernandez 1978) have conducted detailed studies of the germination ecology of this species.

[1]Unpublished data on file with the Agriculture Research Service, Reno, Nev.

Grayia spinosa (Hook.) Moq.

The seeds of G. spinosa are readily germinable without pretreatment (Wood and others 1976). The rapid rate of germination permitted establishment on soils that were dried from field capacity to low matric potentials. The persistent fruiting bracts apparently serve to modify the harsh environment on the surface of seedbeds and aid in germination.

Sarcobatus vermiculatus (Hook.) Torr.

Eddleman (1979) determined that when the membranous pericarp of the S. vermiculatus seed was ruptured, the embryo uncoiled in less than an hour and root hairs developed within 24 hours. With the pericarp intact, rapid imbibition occurred, but germination was slow and many seeds had not germinated after 30 days. The seeds Eddleman tested had increased germination at warm temperatures after cold-moist stratification.

The seeds Eddleman (1979) used in his experiments were collected in southeastern Montana. Apparently, he removed the enclosing papery bracts before initiating trials. We have determined that the enclosing bracts have a decided influence on germination, especially when incubated in moisture-supplying solutions with reduced osmotic potentials.[2]

GERMINATION OF EXTREME HALOPHYTES

The major question in the germination ecology of extreme halophytes is whether germination can occur at extremely low osmotic potentials or if the potentials must be moderated before even the seeds of adapted species can germinate. Chapman (1960) believed that modification of low osmotic potentials was necessary for germination of species adapted to halophytic situations. Ungar (1962) demonstrated that there is apparent adaptation for germination among halophytes at low osmotic potentials.

Osmotic potentials of solutions vary with temperature so one possibility for compensating for low osmotic potentials is for germination to occur at very low incubation temperatures (Rivers and Weher 1971).

Seeds of Salicornia europaea L. have the chenopod germination characteristic--dimorphism. Large seeds are more salt tolerant than small seeds (Ungar 1979).

Dormancy of seeds of Suaeda spp. induced by exposure to low osmotic potentials can be reversed through exogeneous applications of gibberellic acid (Boucand and Ungar 1976). Cytokinic activity in Suaeda seed appeared to be reduced by exposure to low osmotic potentials.

Many of these observations on the germination ecology of extreme halophytes may have application to chenopods in general considering the prevalent salt-affected soils of the Intermountain area.

CONSIDERATIONS FOR FUTURE RESEARCH

The ample evidence of diopolymorphism in the seeds of chenopods makes it essential to consider the occurrence of this germination strategy. Failure to recognize polymorphism probably has produced variability in past germination experiments.

A vital need in understanding the germination ecology of native chenopods is to establish the physical parameters in field seedbeds. Data need to be gathered on temperatures at which germination occurs, and osmotic potentials at the actual time of germination.

A most interesting facet of the germination of chenopods in salt-desert environments is the influence of prolonged soaking of seeds in low osmotic potential solutions at optimal germination temperatures. This phenomenon may be the rule rather than the exception in the ecology of many species of chenopods.

Once dormancy requirements are satisfied, the seeds of many species of chenopod uncoil and develop root hairs extremely rapidly. We need to determine whether this is an adaptation for germination in very transitory environments.

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A TECHNIQUE FOR RETAINING SEED VIABILITY IN KOCHIA PROSTRATA [L.] SCHRAD

Kent R. Jorgensen and James N. Davis

ABSTRACT: Germination was greatly increased by lowering seed moisture by ovendrying and outside storage in an airtight container. Four treatments were devised. There was little difference in germination between treatments the first year. Germination with ovendrying/outside storage during the second and third year respectively was 9 and 23.1 percent higher than ovendrying/inside storage, 28 and 45 percent higher than air-drying/outside storage, and 43.6 and 49.4 percent higher than air-drying/inside storage.

INTRODUCTION

There is an increasing interest in 'Immigrant' forage kochia (*Kochia prostrata* [L.] Schrad) as a desirable half-shrub for revegetation work on our arid and semiarid western ranges. It is highly salt tolerant (Francois 1976), has good forage qualities (Davis 1979), and is a preferred forage for sheep (Menati 1977).

Balyan (1972) found he could maintain higher viability for longer storage periods if moisture content was 6 to 8 percent. He felt seed should be stored at 7 percent moisture in an airtight container to maintain extended viability. Because of the reported loss of viability within 5 to 7 months and high price for the seed (from $16 to $26 per lb or $35 to $57/kg), additional information on seed storage is needed. This study was done to evaluate the effect seed moisture has on seed viability over an extended storage time.

METHODS

'Immigrant' forage kochia seed (P.I. number 314929 - our accession U2) grown at the Snow College Field Station, Ephraim, Utah, was harvested by hand in early November 1979 and allowed to air-dry for 10 days. The seed was then run through a barley debearder to remove seed from the stalks, then through a two-way fan to remove inert material. Seed was stored in 50-lb (23-kg) burlap bags in an open warehouse until February 1980. Two composite samples were removed from the burlap bags. One sample was ovendried at 105° F (40.6° C) for 96 hours, reducing the moisture in the seed to 7 percent, and placed in a vacuum-tight container. A second sample of seed was air-dried to 9.4 percent moisture and placed in a cloth bag where the moisture content could vary with humidity. Control samples with 10.8 percent moisture were taken periodically from seed stored under normal warehouse conditions. Seed samples from the 7 percent and 9.4 percent moisture treatments were divided in two and placed in an open warehouse where the temperature fluctuated from a low of -10° F (-23.3° C) to a high of 75° F (23.8° C), and an office where temperatures ranged from 60° to 80° F (15° to 30° C).

Germination tests were started the first week of March 1980 and continued every 2 weeks until November 1982 when the seed was 3 years old. At the start of each 2-week period, six lots of 100 seeds per treatment were counted; only large plump seeds were used. Seeds were placed between moist paper, then wrapped in plastic and put in a refrigerator where the temperature ranged from 34° F (1.1° C) to 38° F (3.3° C) for 24 hours. Seeds were germinated at room temperature. Counts on germinated seed were made each succeeding day until germination was complete, generally 6 to 7 days. Germination tests were run on the control samples 3, 12, 18, 24, and 36 months after seed harvest. Seed was considered germinated when the hypocotyl length reached 0.2 in (5 mm) (Young and others 1981).

Analysis of variance was used to determine differences in seed germination. Newman-Kuels' multiple means comparison test was used to determine differences between the means.

RESULTS AND DISCUSSION

Both moisture and temperature have a detrimental effect on stored 'Immigrant' forage kochia seed. In table 1, moisture is shown to have a great effect on seed germination, especially when air-dried. During the first year there were no significant differences between inside and outside air-dried seed or inside and outside ovendried seed. There was a significant difference between all treatments

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Table 1.-- Average percent germination for each year of storage.

Years Stored	Air-dried inside storage	Air-dried outside storage	Ovendried inside storage	Ovendried outside storage
1	[1]87.8[a]	85.0[a]	92.6[b]	93.2[b]
2	43.6[a]	54.5[b]	73.5[c]	82.5[d]
3	16.3[a]	20.9[a]	42.6[b]	65.7[c]

[1]Means with the same superscript letter are not significantly (0.5) different.

in the second year. It was also apparent that temperature also had an effect on germination. There was a significant difference within both moisture treatments (air-dried vs. ovendried) with the two different storage temperatures. In the third year there was no significant difference in germination within the air-dried treatment. But the ovendried seed had a significant difference in germination between the two storage temperatures.

We were not able to statistically test our control samples, but germination after the first year was 94.2 percent. It dropped to 9.8 percent the second year. There was no germination the third year.

SUMMARY

Seed from the ovendried/outside storage treatment in an airtight container had the highest overall germination. It went from a high of 93.2 percent the first year to a low of 65.7 percent the third year. We feel that if the seed had been ovendried right after harvesting and cleaned, and kept at a constant 40° F (4.4° C), higher germination through the third year would have been obtained.

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PERICARP INHIBITION OF GERMINATION OF ATRIPLEX CONFERTIFOLIA (TORR. & FREM.) WATS.

Daniel C. Warren and Burgess L. Kay

ABSTRACT: Utricles of Atriplex confertifolia (Torr. and Frem.) Wats. offered no germination response when pericarps remained intact. Five pericarp-dependent mechanisms of germination inhibition are proposed and tested. Mechanical resistance offered the best explanation of complete germination inhibition. Osmotic potential and limited oxygen supply only reduced germination. Tannins in the pericarp did not prevent water conduction. Clipping bracts did not enhance germination. Severe hammermill treatment met with little success. Sulfuric acid and legume scarifier treatments produced no seedlings. Seed fill can be detected inexpensively by soaking fruits for 48 hours at 41°F (5°C). Seed within pericarps became apparent under strong light after soaking. No loss of viability occurred during this treatment.

INTRODUCTION

Germination studies on perennial Atriplex species have reported poor germination responses under artificial conditions (Sabo and others 1979; Lailhacar-Kind and Laude 1975). Germination is sometimes hampered by the presence of an indurated pericarp surrounding the seeds. Several mechanisms may be important in explaining the cause of pericarp inhibition, yet few studies exist that explore these mechanisms.

Much attention has been given to Atriplex repanda Phil. with regard to the role of several potential inhibition mechanisms (Fernandez and Johnston 1978; Johnston and Fernandez 1978), but virtually no data exist in the published literature concerning the inhibitive role of the pericarp in the germination of perennial Atriplex species native to the Mojave Desert or the salt-desert regions within the Great Basin. The species native to these locations have tremendous potential as soil cover plants in areas disturbed by off-road vehicle (ORV) use, construction, or mining, and, therefore, a need exists for work in this area.

In the present study, three species native to the Mojave and Great Basin were tested for their germination response after pericarp removal. Atriplex confertifolia (Torr. & Frem.) Wats. germinated 72 percent of the viable seed after pericarp removal. However, intact utricles consistently would not permit germination. Atriplex hymenelytra (Torr.) Wats., having a softer pericarp, germinated at the same rate whether the pericarp was removed or not. Atriplex spinifera Macbr. contained few viable seed and, therefore, did not germinate whether seeds were excised from the pericarp or not.

The pericarps of A. confertifolia are similar to those of the Chilean native, A. repanda; they are extremely indurated, and not abraded, cut or broken easily. Stutz[1] indicated that the pericarp of A. confertifolia created enough mechanical resistance to radicle emergence to inhibit germination. Removal of the pericarps of Atriplex canescens (Pursh.) Nutt. has been shown to hasten germination, demonstrating that inhibition can be removed in some Atriplex species by simply removing the pericarp (Springfield 1970).

The mechanism of inhibition is ill-defined (Leslie and others 1974). With an understanding of the inhibition mechanism, efforts can be made to circumvent it economically. Some researchers have suggested that salt in the pericarp osmotically inhibits germination by inhibiting imbibition (Beadle 1952; Chatterton and McKell 1969; Koller 1957; West 1969). While it can be shown that pericarps contain sodium chloride, leaching of this water-soluble material does not improve germination of A. confertifolia (Zavon and Kay[2]) The thickness and dense, woody construction of the pericarp may inhibit germination, primarily by preventing adequate water and oxygen from reaching the embryo (Sabo and others 1979; Fernandez and Johnston 1980).

With these mechanisms in mind, work began to evaluate the roles of mechanical, osmotic, and permeability inhibitors of the pericarp.

MATERIALS AND METHODS

Seeds of A. confertifolia used in this study were furnished by Dr. James A. Young, range scientist for the Agricultural Research Service in Reno, Nev. The seeds were collected in December 1977, near Lone Pine Creek, Calif. A. hymenelytra fruits were collected on the west side of Panamint Valley in late spring 1980. A. spinifera fruits were collected on the west shore of Lake El Mirage in August 1980. All fruits were maintained under warehouse condition in cloth or paper bags until the study began, January 1982.

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[1]Stutz, H.C., Prof. of Botany, Brigham Young University, in a letter addressed to Jeff Norton, Univ. of Calif., Davis, Feb. 6, 1980.

[2]Zavon, J.; Kay, B.L., graduate student and wildlands seeding specialist of Dept. of Agronomy and Range Science, Univ. of Calif., Davis, Unpublished data; 1981.

Four replicates of 25 seeds were used in each germination treatment, and germinated in petri dishes at 60°F (15°C). Since natural germination occurs under diurnally varying temperatures, germinating at a constant temperature may have biased the results. Where seeds were excised, as many fruits as it took to yield 25 seeds were used. The number of fruits dissected per treatment was used as the denominator for the germination percentage calculation. Seeds were considered germinated when radicles emerged 0.08 in. (2mm) beyond the testa. Statistical analysis was limited to t-tests done after arcsine transformation was performed on the percentage data (Steel and Torrie 1980).

Comparison of pericarp weight, seed weight, and germination for Atriplex hymenelytra, A. confertifolia, and A. spinifera was performed by excising seed from pericarps in four replicates of 25 fruits for each species and dividing the weights by the number of pericarps or seed within each replicate to give individual seed or pericarp weights. Germination during this comparison was done on four replicates of 25 intact fruits for each species at a constant 60°F (15°C).

A 0.2 percent solution of tetrazolium chloride in distilled water was used to determine viability (Springfield 1970). Four replicates of 25 utricles were used. Utricles were soaked overnight. Seeds were then excised, dissected, and placed in the tetrazolium solution for 24 hours at 41°F (5°C). Radicles that stained red were considered viable. Seed fill percentage was calculated during excision of the seeds for staining. Seed fill is defined as the number of fruits containing well-developed seeds divided by the total number of fruits examined, and expressed as a percentage.

Imbibition rates for A. confertifolia, A. hymenelytra, and A. spinifera were measured by soaking four replicates of 100 utricles of each species, and weighing at 12-hour intervals, after blotting fruits on dry cloth towels. Testing for the presence of a nonwettable layer was done by breaking 50 fruits of A. confertifolia, and placing 0.016 square inch pieces of blotter paper within the pericarp remnants. The pericarp remnants containing the blotter pieces were then placed on moistened blotters in a petri dish, and left overnight. The next day, the colors of the blotter pieces were compared with blotter pieces placed on cellophane, a substance essentially impermeable to water. The cellophane, with dry blotter pieces on top, was in contact with the same moistened substrate as the pericarp remnants. Darkened blotter pieces were considered to have been wetted via conduction of water from the moistened substrate to the blotter pieces.

Water absorption by intact and excised seeds was measured by soaking four replicates of 25 intact utricles, and four replicates of 25 excised seeds before weighing. Both groups soaked for 72 hours. Seeds from intact fruits were then excised, blotted, and weighed. Values were expressed as weight per 100 seeds, although fewer than 100 seeds per replicate were weighed.

Analysis of pericarp leachate was done after grinding four replicates of 100 pericarps followed by extraction in 0.35 oz. (10 ml) of double distilled water, and 2 minutes of agitation. Osmolality was determined with a vapor pressure osmometer. Chloride analysis was done titrametrically, and sodium was analyzed by atomic absorption spectrophotometry. Osmolality of the prepared solutions was converted to osmolality of hydrated pericarps by dividing the weight of osmotica in the solutions by the amount of water absorbed by the pericarps during hydration.

4.2 oz. (120 ml) of 0.197, 0.288, and 0.345 molal leachate was prepared to test the response of seeds to the leachate and, in combination with exposure, to a saturated environment. Nine hundred and forty fruits were used to prepare the 0.197 molal solution, 1,200 fruits for the 0.288 molal solution, and 1,560 fruits for the 0.345 molal solution. The osmolality of these solutions was checked using a vapor pressure osmometer. The saturated environment was prepared by taking strips of cotton, saturating them in the various leachate concentrations, and placing 25 seeds between two strips of saturated cotton for each concentration. This procedure was used in a later experiment using only distilled water to saturate the cotton. Blotters were wetted with leachate to isolate the effect of leachate.

Four replicates of 100 seeds were soaked in petri dishes containing distilled water. Seed volume changes before and after soaking were measured using a graduated cylinder calibrated in 0.0036 oz. (0.1 ml) increments. Denser than water, the seeds sank to the bottom of the cylinder, and the change in the volume contained by the cylinder was recorded at 24-, 48-, and 72-hour intervals.

The pressure produced by swelling of an imbibed seed was measured by applying Van't Hoff's equation to four soaking solutions containing 0.05, 0.20, 0.25, and 0.35 molal sucrose (Nobel 1974). The path of imbibition was observed by weighing excised seeds after soaking for 24, 48, and 72 hours. Petri dishes were used to soak four replicates of 25 seeds per treatment. When seeds soaked for 72 hours showed only a 10 percent increase in fresh weight, the osmotic concentration of the solution was considered to be equal to the pressure the seed could produce during swelling.

Utricles placed on a scale were pressed with a stylus having an area of 0.0012 in^2 (0.077 cm^2), the approximate size of the seed radicle, to measure the strength of the pericarps. The scale reading at the moment of utricle penetration served as the numerator for the calculation of physical pressure required to break the pericarp. Twenty-five utricles, soaked for 24 hours, were pierced to test the effect of wetting on pericarp strength. Twenty-five dry utricles were pierced to measure pericarp strength when dry.

Bract removal was done using a paper cutter. Leaching was done by placing seeds in cheesecloth, then placing the cheesecloth packets in a mason

jar having a screen-mesh lid, through which water was run for 12 hours.

Replacement of seeds in broken pericarps was done to test the effect of pericarp-bound inhibitors on excised seeds. The change in contact area between the pericarp and seed following excision and replacement was of negligible importance to evaluating the response (Sedgeley 1963).

Sulfuric acid treatments used were 0.25-, 0.50-, 1.0-, and 2.0-hour exposures of utricles to 98 percent acid. The hammermill treatment involved placing 3.5 oz. (100g) of utricles in the machine for 5 minutes. The freezing treatment involved soaking four replicates of 25 utricles for 3 days, and then freezing them for 24 hours before incubating 7 days at 60°F (15°C).

RESULTS

Table 1 shows the quantity of sodium chloride and other osmotica bound in hydrated pericarps of A. confertifolia. Table 2 compares the pericarp and seed weights of A. hymenelytra, A. Confertifolia, and A. spinifera and differences in germination among the three species.

Table 1--Analysis and percent composition of sodium chloride in hydrated pericarps of Atriplex confertifolia.

Analysis	Osmolality	Percent composition
	mol/kg	Percent
Sodium	0.045	16.6
Chloride	.034	12.5
Osmolality	.271	100.0

Table 2--Comparison of pericarp weight, seed weight, and germination for Atriplex hymenelytra, A. confertifolia, and A. spinifera.

Species	Weight of pericarp	Weight of seed	Germination
	-----mg	------	Percent
A. hymenelytra	1.22a*	0.906a	45.1a
A. confertifolia	2.76b	0.904a	0
A. spinifera	2.74b	1.078a	0

*Means followed by the same letter are not significantly different at P<5 percent.

Table 3 shows the viability and seed fill of utricles collected from five locations and at different times. The values are consistently low, making germination improvement impossible for the majority of seeds. The Lone Pine Creek accession, collected in December 1977, was chosen for study because of its significantly higher viability and seed fill.

Table 3--Seed viability and fill of Atriplex confertifolia utricles collected in the Mojave Desert.

Location	Date collected	Tetrazolium viability	Fill
		------Percent	-------
Wacoba Springs	5/79	6	9
West Owens Lake	6/79	13	19
Southeast Owens Lake	8/79	17	23
Keeler	11/79	5	7
Lone Pine Creek	12/77	29	38

The germination percentage of seeds excised from pericarps resembled the viability value, yet, when intact, seeds did not germinate (table 4).

Table 4--Germination percentages of Atriplex confertifolia with pericarps excised or intact.

Treatment	Germination percentage
Pericarps excised	21[a]*
Pericarps intact	0[b]
Viability test with tetrazolium	29[a]

*Means followed by the same letter are not significantly different at P<5 percent.

In comparing the rate of water uptake by the utricle, A. confertifolia absorbed water faster during the first 12 hours of soaking than did either A. hymenelytra or A. spinifera (fig. 1). By demonstrating greater pericarp porosity than A. hymenelytra, a species that does not exhibit pericarp inhibition of germination (table 2), A. confertifolia germination is not likely inhibited by pericarp impermeability. Existence of a nonwettable layer between the seed and the pericarp is unlikely. Blotter paper placed inside broken pericarps absorbed water from a moistened substrate via the absorbent pericarp.

Table 5--Fresh weight of intact seed compared with excised seed soaked 72 hours.

Treatment	Fresh Weight Mean	Fresh Weight Std. dev.
	-------g/100 seed	-------
Within pericarp	0.0983	0.0091
Excised	.1335	.035

Weighing hydrated seeds offered a method to test whether the amount of water absorbed by seeds that remained in their pericarps was significantly less than seeds soaked after being excised. Excised seed absorbed more water than seeds that remained within pericarps (table 5).

The significance level of this difference was P<8 percent using a one-tailed t-test at 6 degrees of freedom. The water not absorbed by the intact seeds may have been prevented from entering the seed by some mechanism other than impermeability.

Figure 2 shows germination response to the leachate extracted from a number of pericarps. Analysis of the leachate revealed that 30 percent of the osmotica was sodium chloride. The values given on the abscissa of this graph approximate the low, mean, and high values for the range of solute concentrations inherent to hydrated pericarps. The excised seeds germinated well in the presence of distilled water, but the highest solute concentration significantly decreased germination.

The results of exposing seeds to pericarp leachate was even more dramatic when simulating a low oxygen environment around the germinating seed. When seeds were placed between cotton saturated with the varying leachate concentrations, a significant drop in germination occurred at the lowest leachate concentration. However, this was, undoubtedly, not as much a response to the leachate, as a response to limited oxygen assumed to be characteristic of the saturated cotton environment. Saturation of the cotton with a leachate concentration of 0.345 molal yielded no germination from the exposed seeds. The significance of lowered germination in a solution-saturated environment is that it reflects the conditions that may be present when seeds held within hydrated pericarps are faced with low oxygen availability.

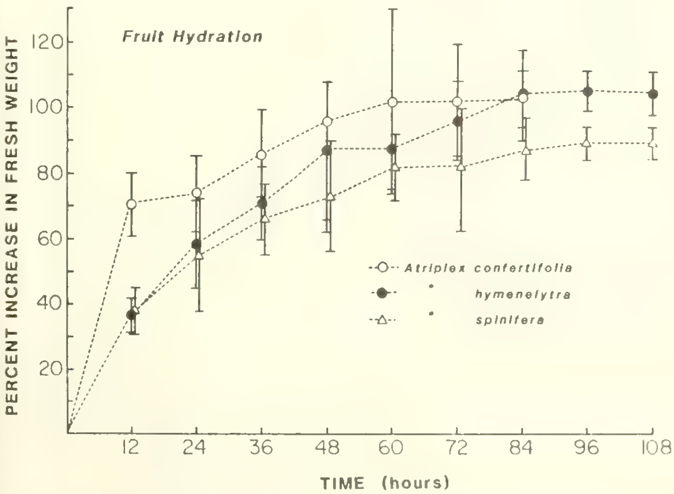

Figure 1--Fruit hydration of A. confertifolia, A. hymenelytra, and A. spinifera weighed at 12-hour intervals for a period of 108 hours.

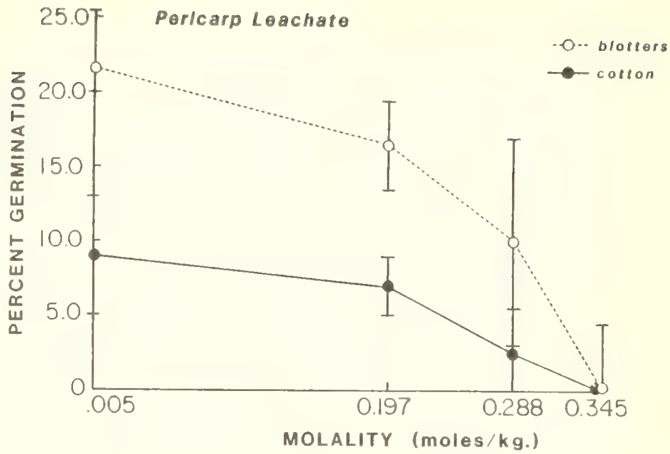

Figure 2--Germination in pericarp leachate of excised A. confertifolia seeds.

Observed early was the extreme tightness with which a seed is held by a pericarp; so much so that seed swelling would likely be inhibited when adequate water is provided for germination. In figure 3, data on seed volume change are plotted as a function of soaking. The change noted after 72 hours of soaking excised seeds was an average of 34.5 percent.

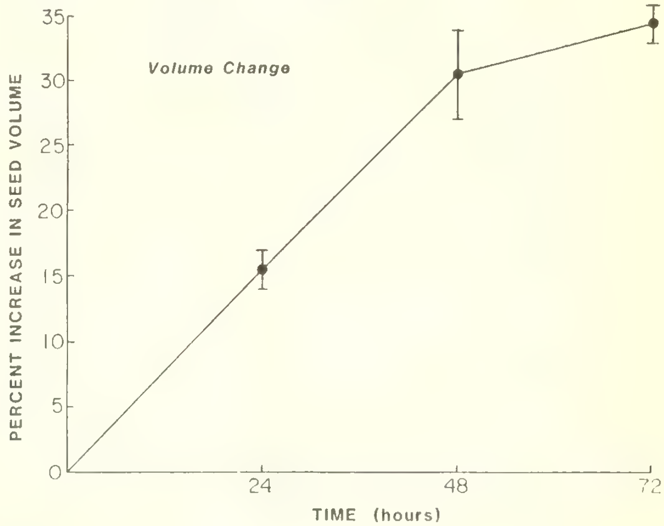

Figure 3--Volume change due to swelling of excised seeds following 3 periods of soaking in distilled water.

In order to facilitate that volume change, which preceeds germination, it is necessary for the seed to break the pericarp by the strength of its potential for water absorption. Expanding seeds continued to swell in solutions as low as -8.52 bars (figure 4). Thus, in pure water, it was assumed the pressure that could be exerted on the pericarp walls was about 8.5 bars (125 psi). In table 6, 8.5 bars, compared with the strength necessary to break pericarps,

reveals the extent to which seed swelling may be inhibited by the presence of the pericarp.

Table 6--Pressure required to break dry and moist pericarps compared with pressure developed by swelling seed.

Pericarp or seed	Pressure Mean	Std. dev.	CV%
	----------Bars----------		
Dry pericarp	302.3	224.5	74
Wet pericarp	115.9	80.5	69
Seed	8.5	--	--

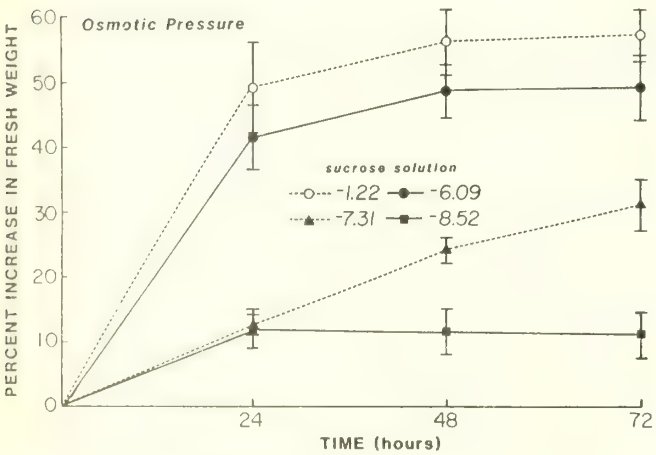

Figure 4--Percent change in fresh weight of excised seeds as a function of bathing in various concentrations of sucrose solutions.

Another plausible mechanism of germination inhibition was the resistance an emerging radicle would meet upon contacting the pericarp wall on its way out. When the bracts were clipped in order to allow radicles free access to the exterior of the pericarp, though, no germination ensued (table 7). The seed swelling and osmotic inhibitors were assumed to be intact. When the pericarps were broken, and the excised seeds were placed back in contact with them, germination occurred. Thus, assuming the broken pericarps mediated water transport to the seed, the salts found in the pericarps did not severely inhibit germination (table 7).

Table 7--Germination of leached fruits, fruits clipped just above the position of the radicle, and seeds excised and replaced inside the dissected pericarp from which they came.

Treatment	Germination
	Percent
Pericarp leached	0
Pericarp clipped	0
Replacement	12.6

Oxygen availability is severely limited when seeds are exposed to a saturated environment, such as that between layers of water-saturated cotton. When this is done to simulate the oxygen status of a seed within a hydrated pericarp, germination is depressed (table 8). However, some germination results.

Table 8--Germination of seeds incubated as follows: Group 1 - excised, placed on moistened blotters; Group 2 - excised, placed between layers of water-saturated cotton; Group 3 - intact utricles placed on moistened blotters.

Treatment	Germination 1st count, 6 days Mean	Std.dev.	Final count 14 days Mean	Std.dev.
Group 1	16.4(a)*	2.1	24.1(a)	3.2
Group 2	5.7(b)	0.8	8.6(b)	3.3
Group 3	0.0(c)	0.0	0.0(c)	0.0

*Means followed by same letter are not significantly different at P<5 percent.

DISCUSSION

The purpose of this research was to explain why germination was completely inhibited if the pericarp was left intact during incubation. Germination after pericarp removal demonstrates consistently that dormancy is maintained by the presence of the pericarp (Sabo and others 1979). The mechanisms investigated in this study point to a number of ways the pericarp might inhibit germination, however, only one mechanism was shown to have the potential for inhibiting germination completely.

After several attempts to enhance germination by leaching and nicking the pericarp in order to remove soluble germination inhibitors, and allow entrance of water and oxygen, still no germination resulted. These results make it clear that no amount of manipulation of the pericarp can

enhance germination short of its removal or weakening.

This experimentation into inhibition of seed swelling is by no means complete. Lack of data for seed volume change after soaking within the pericarp is unfortunate. Using the graduated cylinder to measure volume changes was not amenable to this experiment, because the drying of seeds taken from hydrated fruits results in reduction in density; they float on water (figure 3). Yet, no other mechanism tested here demonstrated the capacity to totally inhibit germination of viable seed.

Efforts to shatter or soften the pericarp by exposure to hammermill, sulfuric acid, or freezing of hydrated pericarps have met with little or no success. The hammermill treatment used offered the greatest success. After liberating 78 seeds from a group of about 1,450 viable utricles, 2.8 percent (40) of the viable seeds actually germinated. Sulfuric acid burned the embryo, and freezing hydrated pericarps did not result in their cracking, which, ostensibly, would have relieved inhibition of seed swelling.

In going through the long process of finding utricles bearing viable seeds, it helps to soak utricles for 24-48 hours, then hold them up to strong light. In most cases, the pericarp becomes translucent, and the seed within can be seen, if present. Seventy-six percent of the seeds found by this method were viable (table 1).

CONCLUSIONS

A pictorial representation of how dormancy regulators may interact in A. confertifolia is presented in figure 5. The various mechanisms all relate to either water or oxygen availability or to mechanical restrictions imposed by the pericarp. The pericarp did not inhibit water uptake via its hardness or density, because its composition was comparatively more hydrophilic than A. hymenelytra, a species which does not demonstrate pericarp inhibition of germination (figure 1). Water uptake by seed of A. confertifolia may be limited due to the reduced driving force for imbibition imposed by the solute concentration within hydrated pericarps. Not explored are the possible toxic effects of solutes or organic inhibitors that may exist.

Resistance to seed swelling can prevent germination (Crocker and Barton 1953). From evidence presented here, no other mechanism explains adequately the lack of germination. The tremendous difference between the pressure required to break pericarps and the pressure developed by swelling seeds shows that pericarps must be severely weakened or removed before germination can be achieved under artificial conditions. However, hammermilling utricles can destroy many more seeds than it liberates.

The attempt to crack and, thus, weaken pericarps by hydration followed by freezing resulted in no germination. The purpose of this procedure was to use the force of the expansion of water during freezing to crack the pericarps like a hammermill, but avoid damaging the seed. Perhaps, this procedure failed because the freezing rate of the ordinary freezer used in this experiment was inadequate.

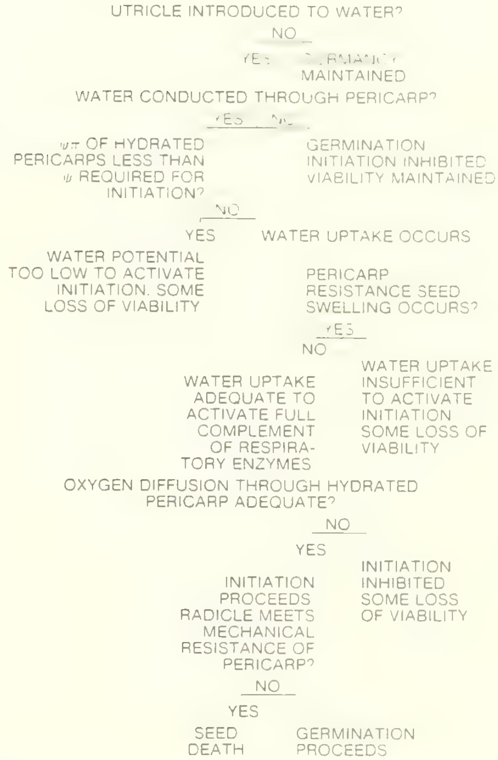

Figure 5--A. confertifolia germination model.

Efforts should be made in three directions to improve germination of A. confertifolia. (1) Varieties having softer pericarps should be selected and developed. The feasibility of this technique is somewhat questionable since most of the work in breeding saltbush is restricted to A. canescens (Carlson[3]). (2) A better hammermilling process should be developed, which minimizes seed destruction while abrading the pericarp sufficiently to break mechanical inhibition. (3) A method of freezing might be developed which actuates pericarp cracking enough to allow seed swelling.

The process of improving germination in A. confertifolia should not concentrate on conventional dormancy breaking treatments such as leaching or stratification (Zavon and Kay[4])

[3]Carlson, J.R., personal communication. Provo, UT; May 1983

[4]Zavon, J.; Kay, B. L., graduate student and wildlands seeding specialist of Dept. of Agronomy and Range Science, Univ. of Calif., Davis. Unpublished data; 1981.

because these methods do not weaken the pericarp sufficiently. Occasionally, when utricles are left outdoors to overwinter dormancy is broken (Roundy[5]). Freezing under natural conditions may crack the pericarp, rather than enhancing the oxygen supply to the seed, which is the conventional mechanism of enhancement occurring during cool-moist stratification (Come and Tissaoui 1972). The objective of germination enhancement under artificial conditions should be to weaken or abrade the pericarp sufficiently to allow seed swelling, while avoiding damage to the seed.

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Section 5. Seed Technology

ATRIPLEX CULTIVAR DEVELOPMENT

Jack R. Carlson

ABSTRACT: The flexibility of Atriplex, with its varying ploidy levels and ability to easily hybridize, makes it a valuable genus for reclamation, forage, and wildlife and livestock habitat improvement projects. The demand for Atriplex seed is substantial and increasing. Wild harvested seed can satisfy most of the demand, but is not widely adaptable. Several cultivars are being extensively tested for wide adaptability to fill this need. Cultivars also provide higher seed yields and seed quality than wild stands. Four Atriplex cultivars are currently available: 'Wytana,' 'Marana,' and 'Rincon' fourwing saltbush, and 'Casa' quailbush. Priority should be given to development of shadscale, gardner saltbush, and other fourwing saltbush cultivars.

INTRODUCTION

Fourwing saltbush (Atriplex canescens [Pursh] Nutt.) currently is the most popular Atriplex species on the commercial seed market. An estimated 20,000 to 30,000 pounds (9,000 to 15,000 kg) of fourwing saltbush seed is collected annually from wild stands and sold for reclamation, range, and wildlife habitat seedings. Demand is substantial (McArthur and others 1978). Stands can be established using wild harvested seed (Plummer and others 1968; Springfield 1970; Graves 1976) and will perform well provided local seed sources are used. However, nearby sources often are not available for seeding projects. Sources farther away will not have proven adaptation unless previous research, by chance, has matched source with the site to be seeded.

Another problem is administrative. Seeding contracts do not always specify local wild seed sources. They often allow poorly adapted seed to be used for the job. "Source identified" classification is used by some state seed certifying agencies and is advocated by the Western Forest and Range Seed Council as a means of formalizing source designations for wild seed and of promoting their proper use in seeding contracts. The "source identified" class requires information on seed purity and germination, or on the pure live seed (PLS) content of each seed lot.

The "source identified" class, however, does not solve the problem of adequate supplies. Widely adapted cultivars will, for several reasons.

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First, a cultivar's wide adaptation is verified by field testing before it is released to commercial seed producers. Because it is widely adapted, a cultivar can be seeded on many more sites than a local source. Therefore, demand for the cultivar is higher and seed companies can afford to keep adequate supplies on hand. In the case of Atriplex cultivars, commercial growers establish and maintain cultivated seed orchards or fields. These orchards or fields usually are planted on good soils and can be irrigated, weeded, and sprayed for insect control, if necessary. As a result, seed yields are higher and more consistent than wild stands, seed quality is increased, and seed supplies are much easier to maintain.

Cultivars are given names, usually signifying a unique characteristic or something about its origin. For instance 'Wytana' is a contraction of Wyoming (Wy) and Montana (tana), indicating the adaptation of this fourwing saltbush cultivar to these two states. Cultivar names tend to promote visibility and acceptance by the contractor, user, seed grower, seed company, and other involved parties.

In the long run, cultivars provide for the most effective use of Atriplex species in revegetation programs because they will best match supply, demand, and performance.

IMPORTANCE OF BROAD GENE BASE

Cultivated varieties undergo a selection and breeding process. Breeders may exert strong selective pressure on several traits. As yields, quality, machine harvestability, and other attributes are enhanced, the gene base of the crop is substantially narrowed. This is common among cereals, corn, and other food crops. Such crops, as experience has shown, are often more vulnerable than wild populations to devastating diseases and insects, if breeders do not provide diversity through an array of suitable cultivars or within the cultivars themselves.

On the other hand, range forage breeders and those who select plants for reclamation emphasize diversity. Here, flexibility, the ability to perform well and reproduce on diverse sites, is a trait that is selected for. Synthetic and composite cultivars can bring several widely separated superior, yet diverse, sources together in one population. Other superior single-source populations may be kept deliberately variable to maintain their flexibility. A broad gene base in range and reclamation cultivars provides this flexibility.

In reclamation plantings, the cultivar should establish, provide effective cover, and produce adequate amounts of seed for future generations. The performance of the cultivar, perhaps, is not as important as the ability of its progeny to effectively occupy a site. Therefore, the seed produced by the cultivar must contain a variety of genotypes that will help the population make the necessary adjustments. In Atriplex, as discussed later, this flexibility can be provided through hybridization, as well as within a broad-base cultivar.

Atriplex is a highly variable and very flexible genus through the interaction of natural variability, polyploidy, and interspecific hybridization (Stutz 1982a, b). The genus lends itself readily to cultivar development, particularly of broad-base reclamation varieties. However, its agronomic potential should not be overlooked. Range sites that are suitable for reseeding to improve forage production and quality are more homogeneous than mine spoils, highway slopes, and borrow pits. Soils on sites suitable for range reseeding, although marginal for cropland, usually are deep, well drained, and fertile. They are unsuitable for cropland because of problems with field logistics or marketing, rather than limitations of the soil. For forage seedings on these sites, perhaps greater selective pressure can be exerted on leafiness, production, crude protein, palatability, and other attributes. The gene base will narrow somewhat, but use of synthetic or composite breeding techniques should prevent cultivars from becoming too narrow.

The potential of a reclamation or forage cultivar is demonstrated through field testing over a wide area under various site conditions. For instance, 'Rincon' fourwing saltbush was released on the basis of its good performance at 29 sites in Arizona, Colorado, Idaho, Oregon, and Utah, for a total of 256 evaluation years. Sites had an average of 9 to 23 inches (23 to 58 cm) of annual precipitation, ranged from 3,000 to 7,600 feet (900 to 2300 m) in elevation, and existing plant communities ranged from sagebrush through pinyon-juniper to mountainbrush.

HYBRIDS AND POLYPLOIDS

Much of the flexibility in Atriplex can be attributed to polyploidy and interspecific hybridization (Stutz and Sanderson 1979; Stutz 1982a). These characteristics have been instrumental in an explosive evolutionary phase for perennial Atriplex species as they invade new habitats produced as a result of the recession of Lake Bonneville in the past 10,000 years (Stutz 1978). The major trends of this evolutionary phase should provide the framework by which cultivars of Atriplex are developed.

According to Stutz, during the most recent ice ages, lakes Bonneville and Lahontan separated two major populations of Atriplex: A. canadensis, an extinct mesophyte to the north, fourwing saltbush to the south. As the lakes receded, both species began to invade the salty bottomlands, came together, and hybridized. From the north, A. canadensis split into three species (fig. 1): A. falcata (M. E. Jones) Standl., A. tridentata Kuntze, and A. gardneri (Moq.) D. Dietr. Fourwing saltbush, migrating from the south, hybridized with all three. It strongly interacted with gardner saltbush forming the subspecies A. c. aptera, which now ranges from Wyoming northward to Montana and the Dakotas. This subspecies is highly variable among populations as it adjusts to different environments throughout its range. Hybrids between fourwing and A. tridentata, because of different ploidy levels, are less stable and usually backcross to either parent (Stutz and others 1979). Hence, some populations of A. tridentata are highly introgressed by fourwing, and vice versa. Similarly, A. falcata has influenced, and has been influenced by, fourwing to the west in Nevada, Idaho, and Oregon. Additionally, in central Nevada, tetraploid fourwing has hybridized with diploid A. falcata, giving rise to the allohexaploid A. canescens nevadensis (Stutz and Sanderson 1979), which is prevalent enough to be considered as a primary germplasm source.

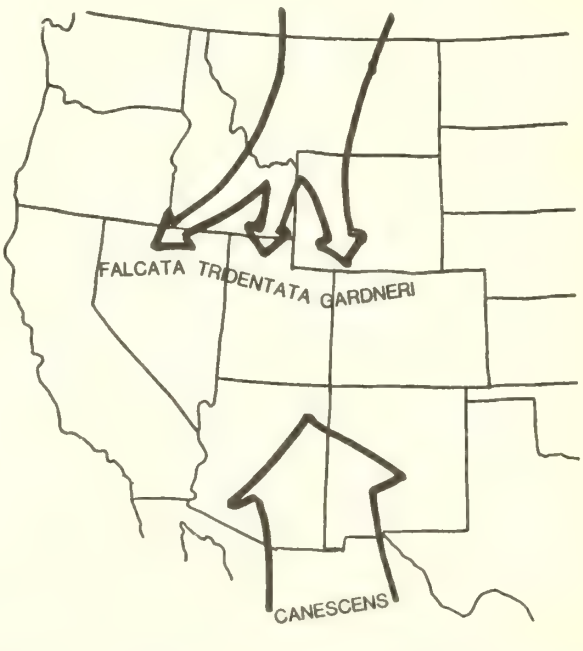

Figure 1.--Migration of A. canadensis and A. canescens populations into former Lake Lahontan and Bonneville area.

Fourwing saltbush has been significantly influenced by three other Atriplex species in the northern half of its range (Stutz 1982a; Blauer and others 1976). It has hybridized with desert saltbush, A. polycarpa (Torr.) S. Wats, in the Mojave and Arizona deserts, losing some of its cold hardiness but gaining drought tolerance. Fourwing also hybridizes with Castle Valley clover, A. corrugata S. Wats., and mat saltbush, A. cuneata A. Nels., but on a much more limited geographic scale than those described above.

In exploring the need for fourwing cultivars, it follows that populations introgressed by other major species would offer major possibilities. Major areas or centers of hybridization between species of Atriplex should be focal points for future cultivar development.

These focal points of hybridization, however, work less well for the second most widespread Atriplex species in the western United States, shadscale, A. confertifolia (Torr. and Frem.) S. Wats. In shadscale's case, polyploidy has been used to adapt to new environments (Stutz 1978). Shadscale primarily occurs in three ploidy levels, each found in a distinct habitat. The relic diploids occur in scattered populations above the Pleistocene lake levels. The autotetraploids are smaller and more compact and have invaded the lake floors in vast expanses. Octoploids, very uniform, short, squat plants, now occupy the lower bottoms. Decaploids also have been found, but only infrequently. However, the plants are vigorous, reversing the trend towards small, compact growth habit.

Ploidy levels also should help shape the direction of cultivar development in Atriplex. Diploid shadscale strains are not likely to perform well on tetraploid sites. For shadscale, the tetraploid form is the most widespread, so a cultivar should be developed for this form, at least. Perhaps another ought to be developed for octoploid sites, although octoploids may be difficult to handle agronomically. Shadscale has been tested very little in field plots, so not much is known of the effect of ploidy levels on site adaptation. However, the distinct natural lines of adaptation by ploidy level indicate the effect is probably strong.

Ploidy level also is an important consideration in other species of Atriplex, such as fourwing and gardner saltbushes, as well as Castle Valley clover. By considering the role of polyploidy with hybridization, we can outline potential sources of new cultivars that will cover most revegetation needs.

Four cultivars of Atriplex native to the western United States are now available. Three are fourwing saltbushes and one a quailbush, A. lentiformis (Torr.) S. Wats.

AVAILABLE ATRIPLEX CULTIVARS

'Wytana' fourwing saltbush was released in 1976 by the USDA Soil Conservation Service (SCS) and the Montana and Wyoming Agricultural Experiment Stations (AES). It originates from central Montana and is typical of the low-growing species in the region. It is a natural hybrid of A. canescens and A. gardneri named A. c. var. aptera (A. Nels) C. Hitchc. 'Wytana' performs very well on coal, uranium, bentonite, and hard rock spoils in Montana and Wyoming. Seed fields can be established and combine harvested using conventional equipment. The first significant commercial seed production fields were established in 1982.

'Marana' fourwing saltbush was released in 1979 for wildlife habitat plantings by SCS, California AES, and the California Department of Fish and Game. Recent tests show 'Marana' to be well adapted for reclamation in southern Arizona and possibly as far east as El Paso, Tex. It has performed well in direct seedings on Mojave Desert roadsides and reclamation seedings near Tucson, Ariz. 'Marana' originates from a population near El Cajon, Calif. (near San Diego). It is vigorous, robust, and tolerant of very hot desert environments. It does not tolerate temperatures below 10°F (-12°C), indicating possible introgression by desert saltbush, A. polycarpa (Torr.) S. Wats., a common occurrence among southern strains of fourwing (Stutz and Sanderson 1979). The ploidy level of 'Marana' is not yet established, but probably is tetraploid. Foundation plants will be available for seed orchards in 1984. About 10,000 plants are produced by commercial nurseries each year.

'Rincon' fourwing saltbush was released in 1982 by the Forest Service Shrub Sciences Laboratory (USFS), Utah Division of Wildlife Resources, SCS, and Colorado and Utah AES. It originates from north-central New Mexico at 8,000-foot (2450 m) elevation and is widely adapted in the Intermountain region (fig. 2). 'Rincon' was selected for superior seed production, annual biomass production, and evergreen condition. 'Rincon' has performed well on diverse sites as far north as Baker County, Oreg., and is recommended for reclamation and range seedings. 'Rincon' is tetraploid and representative of the most widespread form of the species. Crude protein ranges from 18 to 22 percent in leaves in August and November, respectively, and from 7 to 8 percent in stems. Commercial seed orchards were established in 1983.

'Casa' quailbush was released in 1979 for wildlife habitat plantings in California by the same agencies that released 'Marana'. Recent tests show 'Casa' also may be useful in reclamation plantings and range seedings as far east as Tucson, Ariz. Its range of adaptation roughly parallels that of 'Marana' (fig. 2). 'Casa' originates from

San Benito County, Calif. It lacks sufficient cold hardiness to be recommended throughout the range of the species; it cannot be established where temperature drops below 10°F (-12°C). Foundation plants for seed orchards will be available in 1984. About 15,000 plants are produced annually by nurseries.

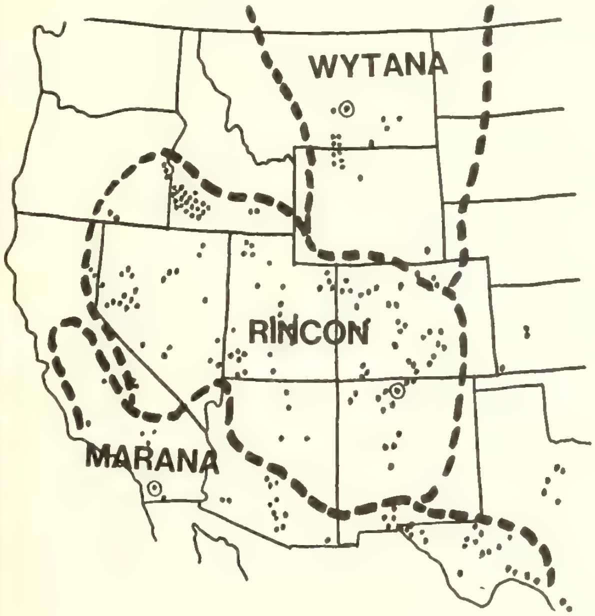

Figure 2.--Ranges of three fourwing saltbush (A. canascens) cultivars.

DEVELOPMENT OF NEW CULTIVARS

Genotypic diversity, hybridization, and polyploidy provide Atriplex with a rich germplasm resource for the development of additional cultivars. The four available cultivars cannot be expected to meet the revegetation needs in the western United States for this important group of plants.

Major Atriplex Species

Fourwing saltbush -- Two additional tetraploid cultivars should be developed; one incorporating attributes from A. tridentata, the other from A. falcata (fig. 3). Five cultivars then would cover the range of the species within the western United States.

To the south, diploid fourwing becomes more prevalent, particularly on sandy soils. In central Nevada, the allohexaploid with A. falcata is extensive. Selections from populations of each should be evaluated against the standard cultivars to determine if further cultivars are needed. If demand is not likely to be sufficient to support another cultivar, perhaps a "source identified" could be applied.

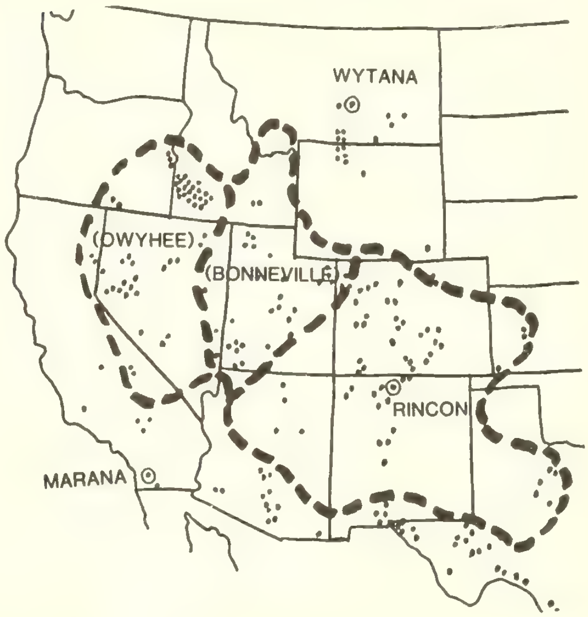

Figure 3.--Potential and available fourwing saltbush cultivars and their respective ranges in the western United States.

Shadscale -- At least a tetraploid cultivar should be developed. An octoploid cultivar would be desirable for dry, harsh, highly saline bottomland sites. However, most reclamation jobs probably involve more upland tetraploid or diploid sites. Major obstacles to shadscale domestication must be overcome, particularly poor seed dormancy and seedling establishment (Blauer and others 1976). However, some accessions recently have been successfully direct seeded in test plots on coal spoil near Rock Springs, Wyoming, and Farmington, New Mexico (SCS 1982).

Gardner saltbush -- This species covers more than 100 million acres (40 million ha), primarily in Wyoming and Montana. It is a dominant plant on many sites disturbed as a result of mining for coal, uranium, bentonite, and other raw materials. Diploids inhabit the uplands; tetraploids occupy bottomland sites. Two cultivars representing each ploidy level may be needed to meet the relatively high reclamation demand for this species. Evaluations are underway by the SCS Bridger Plant Materials Center (PMC) to develop these cultivars.

Desert saltbush -- This species is very drought tolerant and has been successfully seeded on highway slopes in the Mojave Desert (Clary 1983). One accession (PI399195) of desert saltbush, selected from a population near Blythe, Calif., is currently

the leading candidate for release by the Tucson PMC. It appears to be widely adapted through the range of the species. One cultivar should be sufficient for this species.

Other Species

Castle Valley clover and mat saltbush are important species in eastern Utah, western Colorado, and northwestern New Mexico. Because coal, uranium, and hard rock mining, as well as oil shale development, are common in this region, these two species are in moderately high demand for reclamation. Germplasm collection and evaluation have been very limited to date. Both hybridize with fourwing and shadscale as well as each other. Superior accessions should be systematically collected and evaluated for reclamation purposes.

Atriplex falcata and A. tridentata, which introgress into fourwing, are significant species in their own right (figure 4). Cultivars of each would be useful in seed mixtures with fourwing saltbush. Both are lower-growing with good erosion control characteristics.

Figure 4.--General distribution of less widespread Atriplex species for which cultivars ought to be considered.

Forage Cultivars

In additon to its value as a reclamation genus, Atriplex has high agronomic value as a range forage, with many desirable traits. Most forage cultivars will likely be modifications of fourwing saltbush, the most widespread species and highest biomass producer. Drought tolerance is found in desert saltbush, seed harvestability in northern species of Atriplex. Castle Valley clover is more palatable and evergreen than other species. The ease of hybridization in Atriplex offers tremendous possibilities for its use as forage. It is hoped that a forage breeding program will soon be initiated.

Seed Mixtures

Seed mixtures used for reclamation usually include several species and attempt to reestablish, or at least mimic, the displaced native plant community. Many seed mixtures will continue to have Atriplex as a major component. This component should consist of at least the naturally occurring species near the site to be treated. Fourwing saltbush, because it is the most widespread, should form the backbone of most Atriplex seed mixture components.

If cultivars are developed as discussed above, reclamation specialists will be able to include in seed mixtures the Atriplex component best suited for the location and objective of the revegetation job (table 1). For example, for northwestern Utah the Atriplex components may consist of a tetraploid fourwing cultivar (Bonneville strain) introgressed with A. tridentata, an A. tridentata cultivar, and a tetraploid shadscale. Although all would have the potential to establish and provide ground cover, each would serve as a parent for future generations, probably hybrids, that would take over and be better adapted.

Table 1.--Atriplex seed mixture groupings.

Fourwing cultivar	Secondary components
Wytana (tetraploid)	A. confertifolia (tetraploid) A. gardneri (diploid and tetraploid)
Rincon (tetraploid)	A. confertifolia (tetraploid) A. cuneata A. corrugata A. tridentata (hexaploid)
Marana (probably tetraploid)	A. polycarpa (tetraploid) A. lentiformis 'Casa' A. canescens (diploid)
Bonneville strain (tetraploid)	A. confertifolia (tetraploid) A. tridentata (hexaploid) A. falcata (diploid)
Owyhee strain (tetraploid)	A. confertifolia (tetraploid) A. falcata (diploid) A. tridentata (hexaploid) A. c. nevadensis (hexaploid)

On the other hand, a forage seeding of Atriplex, although probably mixed with grasses, legumes, and other shrubs, could be with a single cultivar, perhaps with improved winter forage quality.

PRIORITIES

Given the enormous potential of the genus for reclamation and forage, priorities should be established for cultivar development. Table 2 provides one possible ranking and may represent the direction of the combined effort by several agencies on this group of plants at the present time. Of the high priorities, perhaps shadscale and Gardner saltbush warrant the most intensive effort, because they are critically needed for mine reclamation in the next two decades. 'Rincon' fourwing saltbush is widely adapted and could suffice until the other cultivars of fourwing are developed. However, since fourwing will provide the backbone for most Atriplex seed mixtures, it is advisable that the 'Owyhee' and 'Bonneville' strains be developed. In the long term, a forage variety of fourwing will have a large impact on a balanced forage program for Intermountain rangelands.

Desert saltbush is one of the easiest to directly seed and obtain adequate ground cover in the Sonoran Desert of the Southwest. Therefore, once released, it will be an essential component of our most drought-tolerant seed mixtures. Likewise, although more limited in range, mat saltbush and Castle Valley clover are important species for reclaiming mined lands in eastern Utah and western Colorado.

Other species are somewhat lower priority, but at least adequate germplasm should be assembled and evaluated. Some strains may be valuable sources of genes for infusing into the higher priority species, particularly for a forage cultivar.

Resources probably will not permit development of cultivars for all species and situations. Those who want to use the lower priority species may have to rely on "source identified" classification for seed quality and on local sources for adequate performance. A combination of cultivars and high-quality wild seed sources will be needed to meet the considerable demand for Atriplex.

Table 2.--Priority for cultivar release.

Cultivars	Release
Already released	
Fourwing saltbush (Wytana strain)	1976
Fourwing saltbush (Marana strain)	1979
Quailbush (Casa strain)	1979
Fourwing saltbush (Rincon strain)	1982
High priority	(Projected)
Fourwing saltbush (Owyhee strain)	late 80's
Fourwing saltbush (Bonneville strain)	mid 90's
Shadscale (tetraploid)	mid 90's
Gardner saltbush (diploid)	late 80's
Gardner saltbush (tetraploid)	late 80's
Forage fourwing saltbush	undetermined
Medium priority	
Desert saltbush (Mohave strain)	mid 80's
Castle Valley clover	undetermined
Mat saltbush	undetermined
Lower priority	
A. falcata	undetermined
A. tridentata	undetermined
Fourwing saltbush (diploid)	undetermined
Fourwing saltbush (hexaploid)	undetermined
Shadscale (octaploid)	undetermined

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CONSIDERATIONS IN SELECTING CHENOPOD SPECIES FOR RANGE SEEDINGS

Mark Plummer

ABSTRACT: It is important before selecting chenopod shrub seed for vegetative rehabilitation, that careful consideration be given to the site conditions that will control its establishment and growth. Adaptability of strains, ecotypes, or biotypes to the site should be the primary consideration regardless of cost, since the purchase of seed on the basis of cost alone will most likely result in failure of the planting.

INTRODUCTION

The widespread use of native shrub seed in vegetative rehabilitation has generated a need for more conclusive information about shrub species and how they can be successfully planted (McArthur and others 1978). Suppliers of native shrub seed have an important role to fulfill in marketing seed appropriate for prescribed use.

In many cases, marginal results have been obtained from artificial seedings using native shrub species (Plummer and others 1968). This has caused many to question to what extent shrubs can be successfully established and what limiting factors are involved.[1] These questions most certainly must be addressed. However, before any final conclusions are made based on the success or failure of any one project, it is important to consider the seed planted.

Most of the chenopod shrubs commonly used to improve the quality and productivity of western ranges share common characteristics; that is, they have a wide range of distribution, but local and site characteristics control their occurrence.[2] The evolution and subsequent local adaptation of these shrubs over large areas has caused considerable variation in the germplasm of different populations and individuals. The tendency has been for many strains, ecotypes, and biotypes of the same species to be exhibited on western ranges (Stutz and others 1979). These genetic variants are obviously more adapted to certain localities and sites than others (Plummer and others 1955; Plummer and others 1968; Schopmeyer 1974; McArthur and others 1983).

Many theories have been offered to explain the variation exhibited in chenopod shrubs. However, the objective of this paper is to explain why this is important in the marketing of native shrub seed.

CURRENT MARKETING PRACTICES

Commercial dealers of native seed sell many thousands of pounds of chenopod seed each year for range improvement and reclamation purposes (McArthur and others 1978). Among the species most commonly sold are fourwing saltbush (Atriplex canescens [Pursh] Nutt.), shadscale (Atriplex confertifolia [Torr. & Frem.] Wats.), gardner saltbush (Atriplex gardneri [Moq.] D. Dietr.), and common winterfat (Ceratoides lanata [Pursh] J. T. Howell). With increased commercial availability of chenopod seeds, demand is increasing for other species also. These species include spiny hopsage (Grayia spinosa [Hook.] Moq in DC.), prostrate kochia (Kochia prostrata [L.] Schrad.), falcate saltbush (Atriplex falcata [Jones] Standl.), big saltbush (Atriplex lentiformis [Torr.] Wats.), and black greasewood (Sarcobatus vermiculatus [Hook.] Torr. in Emory).

The recognition and use of these shrubs has greatly increased the amount of seed available from seed companies (table 1). Unfortunately the information essential to successfully grow these shrubs has not been made equally available. In most cases, these seeds are collected from different ranges and widely varying sites; however, in purchase consideration is given only to seed available at the lowest cost.[3] There is increasing evidence that such marketing practices have resulted in the selection of seed not suited for the intended area (Secrist and Sands, these proceedings). It is obvious that more emphasis needs to be given to selecting seed according to origin and site adaptability. The education of the seed industry and consumers to this finding could well determine the success of native shrub seedings in the future.

Mark P. Plummer is the Managing Employee of Plummer Plant and Seed Co., Ephraim, Utah.

[1]Personal communications with several project supervisors; 1983.

[2]Plummer, A. P.; McArthur, E. D. Woody chenopods for reclamation of depleted and spoiled areas on arid ranges. Unpublished paper of Intermountain Forest and Range Experiment Station; 1975.

[3]Data on file at Plummer Plant and Seed Co., Ephraim, Utah.

Table 1.--Chenopod seed sales and collection data.[1]

Species	Developed cultivars	Est. lb. sold annually	Principal areas of collection	Seed crop frequency	Length of storage in years
Atriplex canescens	'Rincon' 'Marana' 'Wytana'	45,000	Western U. S.	yearly	10
Atriplex confertifolia		25,000	Intermountain and Southwest	yearly	10
Atriplex corrugata		2,000	Colorado River Basin, N. New Mexico	yearly	3
Atriplex lentiformis	'Casa'	500	Lower Great Basin	yearly	3
Atriplex gardneri		8,000	Montana, Wyoming, N. E. Utah	yearly	5
Atriplex cuneata		1,000	Colorado River Basin	yearly	8
Atriplex tridentata		1,000	Great Basin	yearly	4
Ceratoides lanata		20,000	Western U. S.	yearly	2
Kochia prostrata	'Immigrant'	100	Commercially grown	yearly	2
Sarcobatus vermiculatus		500	Western U. S.	yearly	5
Grayia spinosa		100	Western U. S.	yearly	2

[1]Table based on survey of major seed companies and supplies, 1982-83.

CONSIDERATIONS FOR SELECTING AND BUYING CHENOPOD SEED

The selection of shrub seed should involve the following considerations so that an ecotype or seed source which grows in conditions similar to those where it will be planted is selected.

Plant characteristics such as growth form, rooting depth, palatability, ease of establishment, and resistance to grazing should also be used in the selection of an adapted species or ecotype.

Growth Form

Many chenopods exhibit variations in growth form. Winterfat strains from the Northwest extending into Montana have been noted to have robust and tall growing forms, as well as shorter growing forms. Large stands of winterfat occur in the Great Basin area of Utah and Nevada. Generally winterfat in large intercompetitive stands tends to have a more short and contracted growth form.[4] As might be expected, border plants and those found in a less competitive association tend to be larger and produce more seed. Collections made by Plummer Plant and Seed Company from central Nevada in 1984 yielded 400 conditioned lb/acre of seed from the borders and edges of large nearly exclusive stands of winterfat, while the amount of seed produced within the stands was so limited it could not be economically harvested. Stevens and others (1977) consider an ecotype near Hatch, Utah, to be a large growth form and list several dwarf ecotypes, also. Southwest ecotypes are likely the largest. Particular notice has been given to a woody spinescent form (Ceratoides lanata var. subspinosa) occuring in the rocky hills of the southern desert shrub ranges of Utah, Arizona, California, and New Mexico.[2]

[4]Data on file at Great Basin Experiment Station, Ephraim, Utah.

Other chenopod species also exhibit this variation. Plummer Plant and Seed Company has made collections of low-growing small utricle forms of fourwing saltbush occurring on alkali flats in southern Nevada. In general, however, their collections comprise taller and large utricle forms.

Soil Type

Soil type also affects the adaptability of chenopod species. Fourwing saltbush, for example, has been observed to grow in sandy to gravelly loams, but some populations have also been found in clay loams.[2] Large areas of Atriplex tridentata occur on the heavy clay soils of the old Lake Bonneville lake bed (Stutz and others 1979). Common winterfat grows through a wide variation of sites and soils. On fine silty soils in desert areas, it often grows in nearly pure stands. The Hatch-type winterfat has been classified as a strain well adapted for juniper-pinyon soil associations (Stevens and others 1977). As already mentioned, the more woody spinescent form of common winterfat grows in the rocky hills of the Southwest.

All chenopods are generally more adapted to the arid alkaline ranges of North America. However, a wide range of tolerance has been demonstrated to alkalinity and high sodium salt concentrations in the soil. Shadscale and greasewood are chenopods with high tolerances to salty soils.[2]

Moisture Requirements

Chenopods differ significantly in their requirements for moisture. Greasewood is found both in well-drained and wetland soils. It frequently occurs in association with other chenopods adapted to saline-sodic soils and soils that are poorly drained, such as iodine bush (Allenrolfea occidentalis [Wats.] Kuntze), and sumpbush (Suaeda spp.). Other species such as spiny hopsage, fourwing saltbush, and Australian saltbush (Atriplex semibaccata R. Br.) are found in drier alkaline soils.[2]

Cold Tolerance

Several chenopods have such a great distribution range that they grow through wide climatic variation. Fourwing saltbush, black greasewood, and common winterfat grow from northern desert shrub ranges in Canada to southern desert shrub ranges in the southwestern United States and Mexico.[2]

This large range of distribution does not, however, infer that these species can be successfully planted throughout this range, but that an ecotype or genetic variant must be selected that will grow in the conditions desired.

With fourwing saltbush, it has been observed that southern ecotypes from warmer climates die out within a period of 3 to 8 years in more northern and colder climates.[4] In contrast, seed from more northerly latitudes has been successfully established in the warmer, more southerly latitudes. Closely associated with this observation and of equal importance is the elevation of the seed source. Sources from higher elevations tend to be more adaptable than those from lower and warmer elevations and in general reflect the greater adaptability of ecotypes from these areas (McArthur and others 1983). In addition, the recommendation that seed from nearby sources be used for vegetative rehabilitation has been substantiated (Van Epps 1975).

It is also important to consider that if proper selections are made, these species can extend their natural range occurrence. Fourwing saltbush and winterfat have been successfully grown in areas formerly dominated by sagebrush (Stevens and others 1977; McArthur and others 1983).

NECESSARY MARKETING CHANGES

The biological and ecological considerations listed above are some of the factors important in the selection of a seed source for a particular site. Unfortunately, most shrub species are often purchased only on the basis of cost and availability.

There are solutions to this problem that have already been developed to regulate the commercial sale of tree seed. A source identification system was initiated in the tree seed industry that identifies seed according to latitude, elevation, and precipitation. Maps have been devised which are zoned and categorized according to measurable factors that influence adaptability. In addition, collectors are issued permits which allow them to collect seed only from prescribed areas.

It is not infeasible to develop a similar system that will give buyers of native shrub species the same advantage in their revegetation efforts. Until such a system is completed, buyers have the responsibility to insist on background information for the seed they are buying. It is recommended that the following information be obtained from seed suppliers before any seed purchase is finalized:

1. Location of the seed source, including county, State, latitude, and National Forest, BLM District, or other land description.

2. Elevation of the seed source.

3. Soil type and description of the associated species.

4. Growth form of the parent plants.

5. Seed purity.

6. Seed germination, including date of the test and by whom the test was done.

7. Date of collection and method of seed storage.

This information must be requested by a buyer since it is not required. Many States do not have laws requiring the labeling of native shrub seed and it is not subject to laws regulating agricultural seed. As a practical matter, however, this information is essential to range managers, and without it they are not able to make good choices.

Contracts and bids generally require germination and purity standards. Nevertheless, there has been dissatisfaction expressed by buyers about failure of seed to meet[4] agreed upon standards of purity and germination.

ACKNOWLEDGMENTS

Plummer Plant and Seed Company extends its thanks to Stephen B. Monsen and E. Durant McArthur for their ideas and support of this paper. This paper represents the combination of substantial research and a realistic overview of current conditions in the seed industry with regard to marketing many native shrub species. We extend our thanks for allowing this paper to be presented and published as part of this symposium.

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SEED PRODUCTION OF *ATRIPLEX CANESCENS* (PURSH)NUTT. IN SOUTHERN ARIZONA

James A. Briggs

ABSTRACT: A vegetatively reproduced orchard of *Atriplex canescens* was established in August 1980 at the Tucson Plant Materials Center. The orchard design required 480 plants per acre (192 plants/ha) with 10 percent being male. Maximum distance of female to male plants was limited to 18 feet (5.5m). Initial harvest in December 1981 yielded 692 pounds of dewinged seed per acre (775kg/ha)--of that, 159 pounds (178kg) was pure live seed.

INTRODUCTION

Atriplex canescens (Pursh)Nutt. is used extensively in range improvement, and mine spoil and other disturbed site reclamation throughout the western United States. During 1980, 14 different companies offered this species for sale. Most of the seed sold was harvested from naturally occurring stands.

In a continuing effort to find and promote superior plants having conservation value, the Soil Conservation Service has released three cultivars--'Wytana,' 'Marana,' and 'Rincon'--from the Bridger, Mont., Lockeford, Calif., and Meeker, Colo. Plant Materials Centers (PMC's), respectively.

Techniques for large scale seed production are needed for wholesale seed producers, and for PMC's needing increased seed supplies for advanced adaptation and performance trials.

The Tucson PMC has evaluated *Atriplex canescens* extensively. Since 1977, 39 accessions have been comparatively evaluated at the Center. Accession T-3553 has consistently shown the best overall performance in both vigor and cover. A seed orchard of T-3553 was established at the Tucson PMC to produce a large quantity of seed for advanced testing and determine the effectiveness of the experimental orchard design.

T-3553 was collected from the Santa Rita Experimental Range located just south of Tucson, Ariz. in 1962. The site is at an elevation of 3,000 feet (914m) with soils described as Anthony fine sandy loam. Average annual precipitation is 11 inches (279mm). The site represents about 1 million acres (400,000 ha) of the upper limits of Major Land Resource Area (MLRA) 40 and lower limits of MLRA 41 in southern Arizona.

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METHODS

The seed orchard at the Tucson PMC was established from plants produced asexually at the PMC. All transplants were grown from stem cuttings segregated by sex of the parent plant. Transplants were used to ensure plants of a known sex within the orchard. Stem cuttings (approximately 1/8 inch [3mm] in diameter) were taken from succulent new growth and from hardwood in February 1980. Cuttings were placed in the greenhouse in aluminum trays containing 100 percent perlite. No rooting hormone was used. Cuttings were misted for 14 seconds every 15 minutes between 10 a.m. and 4 p.m. throughout the root development period. Within 8 weeks, 70 percent of the cuttings had rooted.

In April, the cuttings were transplanted into 4-inch (102mm) plastic pots, containing potting soil (one-third loam, one-third sand, and one-third peat moss and Osmocote--a slow-release fertilizer with 19-6-12 analysis [Osmocote has a release life of approximately 3-4 months]). In June, plants were transplanted to 1-gallon #10 cans and placed outdoors under 50 percent shade for further growth.

On August 27, 1980, plants were transplanted to a one-half acre (.2ha) field plot. Plants were transplanted in two 550-foot (168m) rows, spaced 15 feet (4.6m) apart with 5-foot (1.5m) spacing between plants within the rows. One male plant was planted for every ten female plants (fig. 1).

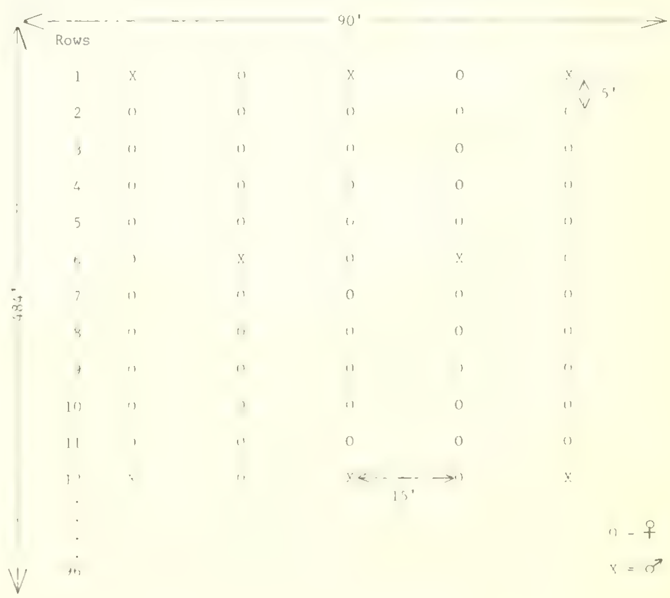

Figure 1.--Orchard design for 1 acre of *Atriplex canescens*. (Only two rows were actually planted at Tucson PMC.)

Plants were hand watered at planting (1/2 gallon [1.9ℓ] of water per plant) and flood irrigated (3 inches [8cm] of water) when planting was completed. Subsequent irrigations were also in 3-inch (8cm) increments. Irrigations through 1982 were as follows:

August 27, 1980	June 30, 1981
September 5, 1980	July 27, 1981
September 19, 1980	August 12, 1981
December 5, 1980	September 18, 1981
March 27, 1981	December 31, 1981
April 28, 1981	May 20, 1982
June 2, 1981	

Only one irrigation was required in 1982 due to above average rainfall (table 1). Two fertilizer applications were made in 1982 totaling 180 pounds of ammonium phosphate (16-20-0) per acre (202kg/ha). The seed orchard was not fertilized in 1983 because large plant size limited equipment operation.

Weed control is minimal due to shading and moisture competition by *A. canescens*. Since 1980, the only required weed control has been selective removal of tumbleweed (*Salsola kali*) and desert broom (*Baccharis sarothroides*).

RESULTS AND DISCUSSION

The orchard was harvested by hand stripping on December 22, 1981, and December 15, 1982. Lack of suitable mechanized equipment required hand stripping. A gasoline-powered, backpack-type vacuum harvester was tried unsuccessfully. There was insufficient suction to dislodge seed from plants. Metal tines were attached to the vacuum, but these too were unsuccessful due to intermittent clogging.

Hand stripping required 5 people working 60 hours to harvest the two 550-foot (168m) rows of T-3553. After harvest, the seed was spread on a protected concrete slab to thoroughly air dry before further seed conditioning. Once completely dried, the seed was milled to remove wings from the fruit. The seed was then processed through an air-screen separator. A total of 277 pounds (126kg) of clean, dewinged fruit was obtained from the two rows.

Based upon the actual two-row yield, a per acre yield of 692 pounds (775kg/ha) of clean, dewinged fruit was obtained from the 1981 harvest. Eight hundred and seventy-five pounds of winged seed per acre (980kg/ha) was harvested in 1982. Based upon past seed conditioning results, a weight reduction of 25 percent in the dewinging process is usual. Reducing the 1982 weight by 25 percent would result in a per-acre yield of 656 pounds of dewinged seed (735kg/ha).

Eighty-two percent of the utricles of the 1981 T-3553 harvest were found to contain seed. Yields of 289 pounds of seed per acre (234kg/ha) with an 85 percent fill have been reported elsewhere (McArthur 1978).

To determine percent fill, 400 fruits were randomly selected and excised. Of the 82 percent of filled fruits, not all appeared healthy. Twenty-five percent of the filled fruits were of low quality. Seed was classified as being of low quality if shriveled or damaged. Subtracting the 25 percent low-quality seed from the total fill of 82 percent results in a fill of 57 percent. The per acre yield of T-3553 then is 429 pounds of seed (480kg/ha), a substantial increase over the 289 pounds (324kg/ha) reported by McArthur.

Yields of two other accessions from the New Mexico and California PMC's have been 50 to 70 pounds per acre (56 to 78kg/ha). These orchards have a much higher percentage of males to females and no attempts were made to optimize the number of seed-bearing plants.

Germination of *A. canescens* T-3553 seed was determined 1 year following harvest. Germination tests

Table 1.--Climatic data at the Tucson Plant Materials Center, averaged for 1980-1982.

Mon	1980 Temperature Avg Max	Avg Min	Max	Min	PPT	1981 Temperature Avg Max	Avg Min	Max	Min	PPT	1982 Temperature Avg Max	Avg Min	Max	Min	PPT
	°F				Inches	°F				Inches	°F				Inches
Jan						67	42	83	32	0.90	62	38	83	28	2.22
Feb						72	41	90	29	.93	68	41	88	30	.46
Mar						71	42	84	36	1.36	71	44	82	32	1.16
Apr						85	53	94	39	.58	82	49	93	39	.00
May						88	57	94	50	.59	88	56	98	47	.14
Jun						102	70	109	62	.06	98	61	107	55	.00
Jul						98	72	107	68	2.66	98	71	107	61	2.61
Aug	97	69	106	60	3.11	97	74	107	65	.51	97	72	105	66	5.21
Sep	95	63	104	55	1.21	95	66	103	56	.48	90	62	102	50	2.14
Oct	84	52	104	38	.45	84	53	94	36	.21	82	45	93	35	.00
Nov	75	41	94	30	.00	79	44	89	33	.75	66	41	80	28	2.08
Dec	73	53	83	30	.29	66	34	86	26	.00	58	32	75	22	2.03
Annual					5.06					9.03					18.05

Table 2.--Germination test results of *Atriplex canescens*.

Lot number	Harvest date	Test date	Percent germination	Remarks
T-3553 at Tucson PMC:				
6076	1978	3/79	26	Range harvest
		[1]6/83	24	
6102	1979	6/81	24	Range harvest
		6/83	14	
		6/83	16	
6125	1979	6/83	9	PMC increase
6164	1980	6/83	8	PMC increase
6224	1980	3/81	18	PMC increase
		6/83	12	
6283	1981	6/83	28	Seed orchard
6318	1982	6/83	11	Seed orchard
'Marana' at Lockeford PMC:				
Blend of	1976-79	7/80	52	
76-77-79		3/81	14	
		10/81	51	
		12/82	44	
T-4474 at Los Lunas PMC:				
SFP-77-JT	1977	3/78	47	Range harvest from Juan Tabo Canyon
		3/80	57	
SFP-78-JT	1978	1/79	29	Range harvest from Juan Tabo Canyon
		8/80	37	
SFP-79-F14	1979	2/80	33	PMC increase
SFP-80-JT	1980	12/80	32	Range harvest
SFP-80-F14	1980	2/81	[2]34	PMC increase
SFP-81-JT	1981	5/82	42	Range harvest
SFP-81-F14	1981	6/82	24	PMC increase

[1]All tests dated 6/83 were performed by Agricultural Labs, Inc.
[2]14 percent dormant.

run at the PMC resulted in 10 percent germination for the 1981 harvest. A tetrazolium chloride (TZ) test (Springfield 1970) was also run on seed of the 1981 harvest. This indicated 14 percent seed viability.

Germination tests performed by Agricultural Seed Laboratories, Inc., Phoenix, Ariz. in June of 1981 indicated germination of 28 percent for the 1981 harvest and 11 percent for the 1982 harvest (table 2). The germination of the 1982 harvest may increase after further ripening (Foiles 1974).

Germination of T-3553 appears lower than other fourwing accessions in the PMC program (table 2). The inherently lower germination of T-3553 may be caused by a high proportion of non-viable gametes. Low viability of filled seeds is common to tetraploid populations of *A. canescens* (Stutz and others 1975). T-3553 appears tetraploid by both appearance and collection site.[1] McArthur (1977) reported tetraploids are able to change sexes under stress with more than half of the population able to do so. In the population studied, a genotype frequency for male and female expression on the same plant was 55 percent with a phenotypic frequency of 10 percent in normal years. Changes of sex have not been noted in the established orchard of T-3553.

[1]Stutz, H. C. Tucson, AZ: Personal communication with author while at Brigham Young University Symposium, 1983.

T-3553 produces seed on first-year wood. Its ability to do this consistently was tested by pruning half of the orchard following initial harvest in 1981. Some plants were severely pruned (90 percent removed) while most were moderately pruned (50 percent removal). Seed production in 1982 was not affected by degree of pruning in 1981.

To assist potential growers of *A. canescens* in southern Arizona, a cost analysis of the PMC's 1981 seed harvest results was run using 1981 cost information for Pima County, Ariz. (Hathorn 1981) (table 3). Total per-acre production cost in 1981 was $942 ($2,328/ha) to produce 692 pounds (314/kg) of dewinged seed. This cost would return a per-acre profit of $787 to $1,133 ($1,944 to $2,798/ha), assuming a wholesale seed price of $2.50 to $3 per pound ($5.50 to $6.60/kg). The 1981 harvest was 159 pounds of pure live seed per acre (178kg/ha) as determined by germination tests in 1983. To obtain profits of $780 to $1,100 per acre ($1,927 to $2,717/ha), seed would have to be priced at $11 to $13 a pound ($24.22 to $28.63/kg) if the seed was sold on a pure live seed basis.

Hand harvesting accounted for 64 percent of the production cost. This cost could be substantially reduced by developing mechanized harvesting techniques and equipment. Irrigation requirements are substantially reduced after establishment.

Table 3.--Cost analysis of fourwing saltbush seed production at the Tucson Plant Materials Center, 1981.

Item	Cost/unit	Unit(s) used	Cost per acre
Irrigation	$ 53.57/acre ft	2 acre ft	$ 107.14
Fertilization:			
Ammonium phosphate (16-20-0)	210.00/ton	180 lb/acre/yr	19.80
Tractor (40 hp)	6.84/h		
Spreader	1.68/h		
Operator	4.00/h		
	12.52/h	1 h/yr	12.52
Cultivation/weed control:			
Tractor (40 hp)	6.84/h		
Rotary hoe	3.74/h		
Operator	4.00/h		
	14.58/h	2 h/yr	29.16
Harvesting:			
Hand stripping	4.00/h	150 manhours/5 rows (1 acre)	600.00
Seed conditioning	20.00/cwt	692 lb	138.40
Total production cost			$ 907.02
Orchard establishment:			
Plants (1-gal size)	0.48/each	approx. 480 plants	$ 230.00
Planting	4.00/h	32 manhours/acre	128.00
Total establishment cost			$ 358.00
Annual cost, assuming a minimum life span of 10 years (Maintenance costs of orchard were not calculated in analysis because of insufficient data at this time)			$ 35.80
Total yearly production cost			$ 942.82

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SEED PRODUCTION TECHNIQUES OF TWO CHENOPODS:

GARDNER SALTBUSH (ATRIPLEX GARDNERI [MOQ.] D. DIETR.) AND WINTERFAT (EUROTIA LANATA [PURSH] MOQ.)

Jack R. Carlson, John G. Scheetz, and Wendall R. Oaks

ABSTRACT: Gardner saltbush (Atriplex gardneri [Moq.] D. Dietr.) and winterfat (Eurotia lanata [Pursh] Moq.) were tested at Soil Conservation Service (SCS) Plant Materials Centers (PMC's) in Bridger, Montana, and Los Lunas, New Mexico, to determine their value as reclamation and forage species on cultivated lands. Management techniques, including seedbed maintenance, harvest methods, and seed cleaning used to achieve optimal seed production, are presented in this paper.

INTRODUCTION

Several chenopods are being grown in irrigated fields and combine-harvested for seed. This paper presents seed production techniques for gardner saltbush (Atriplex gardneri [Moq.] D. Dietr.) and winterfat (Eurotia lanata [Pursh] Moq.). In addition, 'Wytana' fourwing saltbush (A. canescens var. aptera [A. Nels.] C. Hitch.) and 'Corto' Australian saltbush (A. semibaccata R.Br.) have proven to be valuable reclamation and forage cultivars, able to be combine-harvested with conventional seedfield management and harvesting equipment. 'Immigrant' forage kochia (Kochia prostrata [L.] Schrad.), a new chenopod release for range seedings, is also increased with conventional methods.

'Wytana' fourwing saltbush has been cultivated and studied extensively at the Bridger Plant Materials Center in Montana, for several years. Harvest techniques for gardner saltbush are similar. 'Wytana' data are given for the purpose of this study to supplement the data for gardner saltbush. A. canescens var. aptera (A. Nels.) C. Hitch. is a natural cross between fourwing and gardner saltbush. The 'Wytana' strain exhibits strong gardner saltbush characteristics.

In general, the two saltbushes are grown as farm crops under irrigation, swathed when seeds mature each year (beginning the second year), and combine-harvested. The stands are rotary mowed each fall to a 3-inch (8-cm) stubble height to manipulate the growth form of the plants. The numerous decumbent laterals thus left produce seed-bearing shoots the following year. Harvested seed is processed using a hammermill and four-screen air cleaner.

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GARDNER SALTBUSH

The seed production steps outlined by Stroh and Thornberg (1969) for 'Wytana' can be followed with slight modifications.

Gardner saltbush (A. gardneri [Moq.] D. Dietr.) was collected from a wild stand approximately 15 miles (24 km) south of Plevna in Fallon County, southeast Montana. The population was a layering type growing in colonies of 10 foot (3 m) diameter plants. The site was a cut slope of shaley clay at an elevation of 3,000 feet (915 m). Average annual precipitation is 12 inches (30 cm). The ploidy level is not known. However, the accession (labeled T5294) was collected from an upland site, and most upland sites are occupied by diploids. T5294 was planted at the Bridger PMC in a small increase plot in April 1969. This plot was harvested by hand for 6 years, resulting in 44.2 total pounds (20.9 kg) of clean seed. Converted average annual production was 433 pounds per acre (485kg/ha) (table 1).

Table 1.--Seed harvests from two plots of gardner saltbush, Bridger, Mont., 1970-79.

Field	Year	Irrigation (in.)	Fertilizer	Date Harvested	Clean Seed (lbs)	Yield (lbs/acre)
0.017	1970	6	0	10/16	13.3	780
acres	1971	9	0	10/14	15.7	924
planted	1972	0	0	10/18	2.4	139
4/15/69	1973	6	0	10/16	5.1	302
hand	1974	8	0	10/9	4.7	279
harvest	1975	6	0	10/9	3.0	179
Average		5.8	0	10/14		433
Total					44.2	
0.55	1975	6	0	10/3	101.2	185
acres	1976	3	0	10/14	68.8	125
planted	1977	6	0	9/26	40.2	73
11/30/73	1978	6	0	10/17	100.1	182
combine	1979	6	0	9/20	78.1	142
harvest						
Average		5.4	0	10/4		141
Total					389.0	
			Total		433.2	152

A larger field of about one-half acre (about 1/5 hectare) was planted in November 1973. This field was combine-harvested five times from 1975 to 1979. A total of 389 pounds (177 kg) of clean seed was produced, for an average annual yield of 141 pounds per acre (159 kg/ha). The difference between hand-collected and combine-harvested yields reflects difficulties with swathing the low, prostrate plants and the tendency of seeds to shatter. Changes in management techniques and harvesting might improve yields for large-scale production.

Seed Field Establishment

Like most cultivated crops, gardner saltbush requires a firm, weed-free seedbed, particularly when no herbicide program is used for seedling establishment. Fields should be direct seeded in cultivated rows with a dormant fall planting. At Bridger, fields are planted between October 15 and February 15 in 36-inch (90-cm) rows. Spring plantings in April or May are also possible. Plant 20 pure live seeds (PLS) per foot (30 cm) of row. Normally this results in 40 to 50 utricles per foot of row. At Bridger, a grass drill with depth band-controlled, double-disk openers places seed no deeper than one-half inch in the soil.

During the first year, weed control is the most important consideration. Fields are cultivated two to three times, depending on need, with standard cultivator blades and furrow openers on a tool bar. Hand hoeing is necessary, at least once, to remove weeds within the row. Fields are furrow irrigated to keep soil moisture above 50 percent field capacity. By September, plants are about 12 to 18 inches (30-46 cm) tall and wide. After several killing frosts (no later than the third week of November) the field is mowed to a 3-inch (8-cm) stubble height with a 7-foot (2.1-m) rotary mower.

In the second year, young shoots emerge from the prostrate stubble and achieve full canopy by mid-to-late summer. The field is cultivated once or twice and hand hoed at least once. Irrigation is reduced to once before flowering, and once after, following the recommendation of Johnson (1975).

Seed Harvest

Seeds begin to mature during September at Bridger. Harvest is as early as September 20, and as late as October 18. The field is first cut and windrowed with a hay swather. This permits some immature seed to ripen in the windrow. The harvested crop is then picked up with a conventional grain combine. Table 2 provides the settings for two combines used at Bridger for 'Wytana' fourwing saltbush. Only one of the combines has been used to harvest gardner saltbush.

Table 2.--Settings for two combines used to harvest gardner and fourwing saltbushes at Bridger, Mont.

Combine	Gardner saltbush	'Wytana' fourwing saltbush
Allis-Chalmers-72		
Cylinder speed	1,450 rpm	900 rpm
Screen	1/4 inch	9/16 inch
Cylinder spacing	3/16 inch	5/8 inch
Air	1/2 open	3/4 open
International Harvester-615		
Cylinder speed	-	925 rpm
Cylinder clearance	-	5/8 inch
Wind	-	500-640 rpm
Top chaffer	-	1/3 open
Bottom chaffer	-	1/3 open
Concave	-	1/2 closed

Low prostrate growth and the tendency of its seed to shatter, even with minimal handling, make gardner saltbush difficult to harvest. A vacuum harvester salvaged 100 pounds per acre (113 kg/ha) of shattered seed of 'Wytana' at Bridger in 1978. Similar results could be expected with gardner saltbush, although it has not been tried.

Managing Established Fields

Harvested fields are rotary mowed before the third week of November to a 3-inch (8-cm) stubble to macerate and distribute the combine-screening residue. Simizine, although not labeled for use on gardner saltbush, has been applied at a rate of 2 pounds per acre (2.2 kg/ha) on an experimental basis in the fall or early spring. This has helped to control weeds with no noticeable damage to the stand or to seed production.

Stroh and Thornberg (1969) preferred direct combine to swath-and-combine harvesting to reduce the shattering loss from 50 to 20 percent. Since then, however, swath-and-combine harvesting has been practiced to avoid machine clogging, inefficient screening, and increased drying time in storage associated with direct combining of fresh stems.

Management of the third and following years' fields is the same as for the second year. In early spring, before green-up, to provide additional weed control, a field may be rotary-hoed on the diagonal to the cultivated rows. A springtooth harrow also has been used successfully, but more plants are lost than with the rotary hoe.

Although gardner saltbush has not been grown on a field scale for more than five harvests, fields probably could be maintained longer without appreciable yield losses. 'Wytana' has been maintained for eight harvests at Bridger. Five to eight years field life is comparable to grass seed fields.

Seed Cleaning

Gardner saltbush seed is easily cleaned with standard screening and fanning equipment to remove dirt, trash, and weed seed. Seed does not have to be hammermilled. Table 3 provides the settings for the cleaning equipment used at Bridger.

Table 3.--Settings for M2B clipper cleaner used to clean seed of gardner saltbush at Bridger, Mont.

Cycle	Speed	Top screen	Bottom screen	Air-top slide opening	Air-bottom slide opening
1	350 rpm	#15	blank	8 inches	closed
2	350 rpm	#12	No.1-13	8 inches	closed

T5294 gardner saltbush averages 77,000 seeds per pound (169,000 seeds per kg), cleaned. Purity and germination statistics average about 95 percent purity, 40 to 50 percent fill based on tetrazolium (TZ) test, and 10 to 20 percent germination.

WINTERFAT

Winterfat (Eurotia lanata [Pursh] Moq.), considered by many to be Ceratoides lanata (Pursh) J.T. Howell, has been grown for seed at the Los Lunas PMC in central New Mexico since 1974. T4549, the strain planted, originated from a wild stand collected in 1958 about 60 miles (96 km) north of the PMC near San Luis in Sandoval County.

In April 1974, a 0.19-acre (0.08-ha) field was direct seeded to winterfat for seed production. In November of the same year, 6 pounds (2.7 kg) of clean seed was direct combine harvested (table 4). The following spring the field was enlarged by direct seeding an additional 0.66 acre (0.26 ha). This 0.85-acre (0.34-ha) field was harvested each year between 1975 and 1981, producing a total 235 bulk pounds (107 kg) of clean seed. Average production for each of eight harvests was 35 pounds per acre (40 kg/ha).

Table 4.--Harvests from seed fields of winterfat at Los Lunas, N. Mex., 1974-81.

Year	Acreage	Date harvested	Bulk pounds	Yield pounds per acre	PLS factor	PLS per acre
1974	0.19	11-7	6.0	32	-	-
1975	0.85	10-30	38.5	45	0.43	19
1976	0.85	11-1	64.0	75	0.34	26
1977	0.85	10-31	43.0	51	0.51	26
1978	0.85	-	10.0	12	-	-
1979	0.85	11-16	3.5	4	0.63	2
1980	0.85	-	33.0	39	-	-
1981	0.85	-	37.0	44	-	-

Harvests during 1978 and 1979 were much lower than expected. Simazine, at 2 pounds per acre (2.2 kg/ha), was applied in late winter from 1976 to 1979. By 1979, the field was considerably weakened. Simazine treatment was discontinued, and the field responded with somewhat greater vigor and improved seed production. Removing the 1978 and 1979 yield figures results in an average annual production of 43 pounds per acre (49 kg/ha), a 26 percent increase.

Top yield was 75 pounds per acre (85 kg/ha) in 1976 with 34 percent PLS (pure live seed), or 26 pounds PLS per acre. At 175,000 seeds per pound (385,000 seeds per kg), these production figures are low compared to most grasses and to the saltbushes reported in this paper.

Los Lunas currently is evaluating 53 new accessions of winterfat for improved seed production. The 'Hatch' strain (T7844) of winterfat, selected by the USDA Forest Service Shrub Sciences Laboratory, was established in a small field at Los Lunas in 1983, and may have a higher seed production potential than T4549. In a small plot evaluation at Aberdeen, Idaho, T7844 produced more than twice as much seed as eight other strains which had been selected for overall performance from a uniform garden nursery of 40 accessions.[1] T7844 originates near Hatch, Utah, 125 miles (200 km) north of San Luis, New Mexico. Hatch is 355 miles (568 km) south of Aberdeen. It is interesting that T7844 produces so well at Aberdeen, whereas T4549 blooms 30 to 45 days later and fails to pro-

[1]SCS, 1981, unpublished.

duce mature seed. The Aberdeen data indicate a wide variation in seed production among accessions, and latitude could be a major factor. The effect of moving winterfat accessions south of their origin for seed production is not yet known.

Although much remains to be learned about seed production of winterfat, guidelines can be established that will help in choosing accessions that should provide yields at least comparable to those at Los Lunas. Only local sources of winterfat, within 150 miles (250 km) of the proposed seed field, should be used to establish fields. Once an accession has been chosen, the following cultivation and harvesting techniques should be used to ensure optimal production.

Seed Field Establishment

Like gardner saltbush, winterfat requires a firm, weed-free seedbed for adequate germination and establishment. At Los Lunas, 36-inch (90-cm) rows are direct seeded no deeper than one-eighth inch (3 mm), with a Planet Junior shoe drill or conventional vegetable planter. Seeds with utricles removed are planted at a rate of 1.5 pounds per acre (1.7 kg/ha), or 20 pure live seed per foot of row. Seeded fields are kept moist with sprinkler irrigation until germinated seedlings send a root deep enough to permit less frequent irrigation.

Once seedlings are established and rows are distinguishable, fields are cultivated and hoed as needed to take out common weeds such as mustard, annual kochia, and pigweed. Three cultivations and hoeings are usually required. Irrigation is cut back to once every three weeks, enough to maintain soil moisture at 50 percent field capacity and produce vigorous growth. By the end of the first growing season, plants are 2 to 3 feet (0.7 to 1 m) high and have produced a harvestable seed crop.

Seed Harvest

Seed usually matures by late October. Combine harvest at Los Lunas has ranged from October 30 to November 16. Fields are direct-combined with a small grain harvester when seeds begin to shatter. Combine settings are provided in table 5. All air is closed off and very little litter or residue is separated from the seed by the combine. A very small amount of seed is lost as only very large material exits the combine via the straw walkers. Combine stubble height is 6 to 8 inches (15 to 20 cm).

Table 5.--Combine settings used to harvest winterfat at Los Lunas, N. Mex.

	Allis-Chalmers Gleaner K	International Harvestor 205
Cylinder spacing	1/4 inch	various
Cylinder speed	800 rpm	various
Ground speed	0.8 mph	0.8 mph
Screens	removed	removed

Managing Established Fields

Irrigation water is withheld during the spring, as late as possible, to prevent cool-season weed infestations. Although Simazine has been very effective in controlling weeds, it stresses established winterfat plants, inviting common root and foliar diseases, and should not be used. Irrigation also should be as infrequent as possible but enough to maintain plant vigor. Winterfat is very drought tolerant and should produce good seed with limited water. No fertilizer is applied at any time.

Established fields are cultivated and hoed two or three times each year to remove warm-season weeds. Surflan is being applied on an experimental basis at Los Lunas, but it is too early to tell whether it will be beneficial.

Seed fields apparently can be maintained for at least 10 years if kept weed-free and properly managed. Seedling establishment appears to be a major difficulty. New seedings at Los Lunas in 1981 and 1983 have been difficult to establish because of weed competition and the strict planting and irrigation techniques required for shallow seedings.

Seed Cleaning

Harvested seed has usually been hammermilled to remove the fluffy utricles. However, Booth (1982) reports better establishment by seeding whole fruits because utricle hairs anchor the seed to the soil surface and hammermilling damages seeds, thereby reducing seedling vigor. Hammermilling may be a questionable procedure; however, if not hammermilled, fruits may be difficult to separate from stems, leaves, and other litter collected in the field. Hammermilled seed can be effectively separated using a four-screen air seed cleaner. Threshed seeds are also easier to feed through conventional seeding equipment.

Cleanings from the first three screens are rehammermilled and run through the seed cleaner again. A disk separator is used to separate seed from fuzz and other minute residues. Table 6 presents cleaning equipment settings. This process has resulted in as high as 79 percent purity and 80 percent germination, or 63 percent PLS. However, PLS has been as low as 34 percent, indicating processing can be tricky. Not hammermilling may result in PLS of 30 percent or lower. More testing is needed to determine how to clean nonhammermilled seed. The advantages of leaving utricles and fruits intact may outweigh lower PLS percentages and the more difficult seeding methods for trashy seeds.

Table 6.--Seed cleaning equipment settings for winterfat processing at Los Lunas, N. Mex.

Equipment	Setting	Amount
Hammermill	speed	800 rpm
	clearance	1/4 inch
Clipper Model 297D four-screen air cleaner	top screen	#10
	second screen	#9
	third screen	#8
	bottom screen	1/14th
	fan	200 rpm
	upper air	1/4 open
	lower air	1/3 open
	shaker speed	500

T4549 winterfat averages about 175,000 hammermilled seeds per pound (385,000 seeds/kg). Nonhammermilled seed lots vary depending on purity and should be computed individually.

Unless carefully stored, winterfat seed deteriorates rapidly after harvest. Kay and others (1977) found that seed lots with a dessicant added maintained germination for at least 3 years; untreated seed was not viable 6 months after harvest. Springfield (1974) successfully stored winterfat seeds in sealed containers under refrigeration for 8 years. Unless proper large-scale storage facilities are available, seed should be planted soon after harvest, preferably within 6 months.

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ESTABLISHMENT AND INITIAL RESULTS FROM A 'RINCON' FOURWING SALTBUSH (ATRIPLEX CANESCENS [PURSH] NUTT.) SEED ORCHARD

Gary L. Noller, Sam E. Stranathan, and E. Durant McArthur

ABSTRACT: A 'Rincon' fourwing saltbush seed production orchard was established at the Meeker, Colo., Plant Materials Center in 1980 to evaluate its performance and to examine the seed production characteristics. Two replications of cloned and seedling plants were established. Survival in 1982 averaged 94.7 percent. Cloned plants had slightly better survival than seedlings. Seed production was first noted in 1981. Seed hand-harvested in 1982 averaged 117.3 pounds per acre (131.5 kg/ha), considering clones and seedlings together. Each of the two replications of clones produced more seed than either of the two replications of seedlings.

INTRODUCTION

A 'Rincon' fourwing saltbush (Atriplex canescens [Pursh] Nutt.) orchard was established at the Upper Colorado Environmental Plant Center (UCEPC), Meeker, Colo. The orchard was established to evaluate the performance of 'Rincon' at Meeker and to examine its seed production characteristics. 'Rincon' is a cultivar of fourwing saltbush, recently released by the Shrub Sciences Laboratory, Utah Division of Wildlife Resources, UCEPC, Soil Conservation Service, and the Agriculture Experiment Stations of both Utah State and Colorado State Universities[1].

The initial seed collection of 'Rincon' was made in 1957 at Rincon Blanco, three miles northwest of Canjilon, Rio Arriba County, N. Mex. The elevation of the site is 7,800 feet (2,377 m) and it receives about 15 inches (38.1 cm) of annual precipitation. Basin big sagebrush (Artemisia tridentata [Nutt.] spp. tridentata), fourwing saltbush, and seeded wheatgrasses (Agropyron spp. Gaertn.) are the most common plants on the collection site.

[1]McArthur, E. D., Stranathan, S. E., Noller, G. L. 'Rincon' fourwing saltbush--proven for better forage and reclamation. Rangelands. In press.

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'Rincon' was selected for release because of its wide area of adaptation, sustained forage production, erect growth form, and tendency to be evergreen. The area of adaptation for 'Rincon' is situated between the areas of adaptation for the other two cultivars of fourwing saltbush--'Marana' and 'Wytana' (fig. 1).

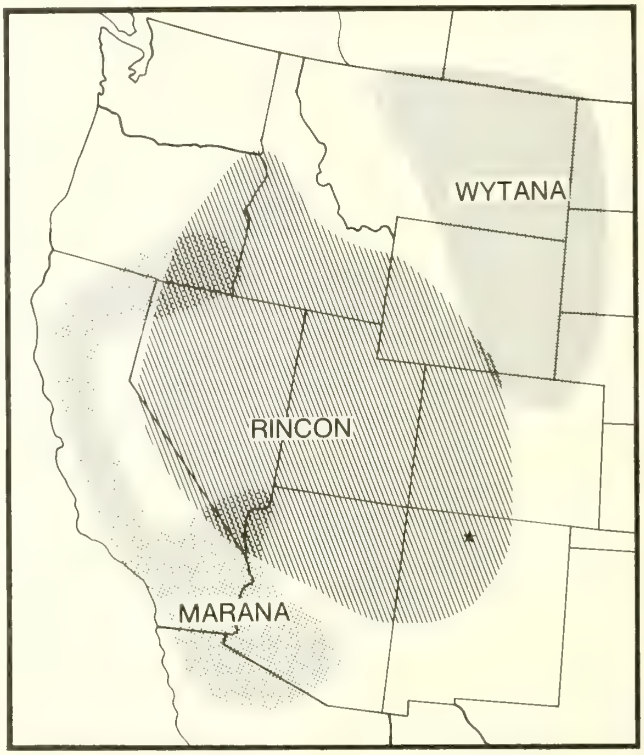

Figure 1.--Map showing adaptation of 'Rincon' fourwing saltbush. Original collection site:★ Areas recommended for planting cultivars are shaded.

MATERIALS AND METHODS

The climatic conditions at the Meeker plant center are characterized by 16.19 inches (41.1 cm) of annual precipitation, 6,500 feet (1,981.2 m) elevation, and a 90-day frost-free growing season. Winter temperatures of -20° to -30° F (-28.9° to -34.4° C) are not unusual. Soils are silt-loam to silty-clay-loam. These conditions may be approaching the distribution limits for fourwing saltbush.

The field where 'Rincon' was planted was fallowed the year before planting and was relatively weed free at planting time. Nitrogen, phosphorus fertilizer (18-46-0) was applied at the rate of 100 lb per acre (112.1 kg/ha) and was disked in before planting.

The 'Rincon' orchard was planted May 27, 1980. The orchard design was a modification of the one presented by McArthur and others (1978) and was designed to accommodate field maintenance equipment, provide adequate pollen flow, and maximize seed production per acre (fig. 2).

Planting

Two replications of seedlings and clones were planted. The seedling plants were produced from seed; the cloned plants were propagated vegetatively from stem cuttings. Plants were spaced 9 feet (2.7 m) apart on the east-west axis and 12 feet (3.7 m) apart on the north-south axis. Cloned plants were planted in a ratio of one row of males to five rows of females. The rows were planted so the prevailing southwest winds during the pollination season could carry the pollen from the males to the females (fig. 2). Each row of females represented a particular numbered female, which was replicated three times in each planting of clones. These numbers refer to a planting in Utah from which the vegetative cuttings were taken to establish the Meeker orchard. The number for the cloned females represents a row, and the number of the plant within the row, from which the cuttings were taken. For example, 8-56 refers to plant 56 in row 8. Soil in the two replications of clones did appear to be different. The southwest replication of clones had an area with white surface soil. This was due to the uneven application of topsoil after the field was leveled for irrigation.

A total of 1,012 plants were planted in the orchard (506 seedlings and 506 clones). Holes were dug, water was added, and potted plants (provided by the Shrub Sciences Laboratory) were inserted and covered. Eight people using a truck and trailer completed the 3.1-acre (1.3-ha) planting in about 5 hours.

Field Maintenance

Watering.--The need for watering was influenced by the weather conditions. In 1980, only 14.63 inches (37.2 cm) of precipitation were recorded. The plants were watered when planted, watered again in mid-June and given an additional watering in mid-August. Approximately 1 gallon (3.8 l) of water was applied at the time of planting. Each irrigation application represented about 1-½ to 2 inches (3.8 - 5.1 cm). The year 1981 was considered wet with 19.02 inches (48.3 cm) of precipitation. No additional water was needed. The orchard was watered once in 1982 on about June 20. Rain occurred later in summer so no additional water was necessary. Precipitation for 1982 totaled only 14.84 inches (37.7 cm).

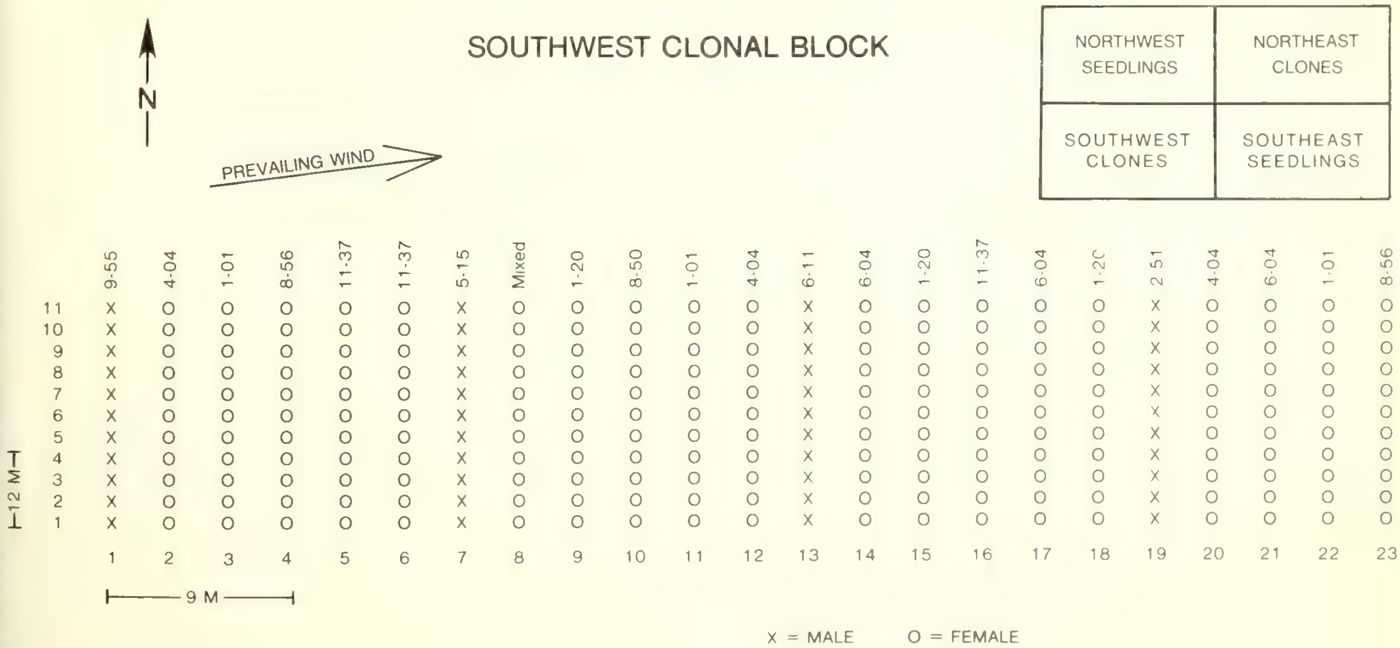

Figure 2.--'Rincon' orchard design showing the two replications of clones and seedlings. Each replication had plants spaced 9 feet (2.7 m) on east-west axis and 12 feet (3.7 m) on north-south axis. Cloned replications were planted in a ratio of one row of males to five rows of females. The numbered female and male rows are shown for the southwest replication.

The June watering in 1982 was important because it gave the plants an opportunity for early summer growth. This early growth was beneficial for taking cuttings for new seed orchard establishment.

Cultivation and weeding.--Cultivation and weeding were done in an attempt to prevent weeds from producing seed in the orchard. The 'Rincon' orchard has been maintained relatively weed free.

The orchard was hand-weeded approximately three times per year and mechanically cultivated with a tractor and a sweep-type cultivator approximately five times per year. The tractor was used to cultivate between the rows of 'Rincon' plants. However, at the present time, it is possible to cultivate with the tractor and 8-foot tool bar in only one direction, east and west.

Herbicides.--Shortly after planting, DCPA (Dacthal) was applied around the fourwing saltbush plants to reduce the germination of annual grasses and broadleaf species. DCPA was applied at a rate of 15 lb per acre (16.8 kg/ha) in a band treatment covering approximately one foot (30.5 cm) on each side of the plants.

Glyphosate (Roundup) was used as a spot treatment for control of Canada thistle (*Cirsium arvense* [L.] Scop.) and volunteer alfalfa (*Medicago sativa* [L.]).

Insect and disease control.--So far, there have been essentially no insect or disease problems in the 'Rincon' orchard. Potential insect or disease problems are monitored.

Data Collection

The 'Rincon' orchard has been evaluated at least once each year. The evaluations were made in mid-to late summer. Values were recorded for survival, vigor, height and crown growth, sex expression, and seed production. Height and crown growth were measured in centimeters and represent the tallest and widest growth of each plant. Numerical reproduction values represent an estimate of the abundance of male or female flowers (0 = none and 9 = abundant flowers). Vigor in general is an estimation of the quality and quantity of growth. Vigor of the plants was estimated and given a numerical value (1 = low and 9 = high vigor).

Data analysis.--Data were analyzed by analysis of variance with Student-Newman-Keuls comparison of means when appropriate and by chi-square analysis (Woolf 1968).

RESULTS

Survival

Survival of the entire 'Rincon' orchard to the fall of 1982 has been good. By the fall of 1980 (mid-to late September, approximately 4 months after planting) survival for the entire orchard averaged 98.7 percent (table 1). Seedling and clone survival were essentially the same, 99.0 percent and 98.4 percent, respectively. Mortality in the replications of clones in 1980 was attributed largely to the loss of one numbered female (8-56), which appeared to be somewhat desiccated at the time of planting. All of the males in both replications of clones were still alive.

In mid-July 1981, all dead plants were replaced. A total of ten seedlings were replaced, four in the northwest replication and six in the southeast replication. Twelve plants from the two replications of clones were replaced. Nine females from the southwest replication of clones were replaced (5 plants of 8-56, 2 plants of mixed, 1 plant of 1-01, and 1 plant of 6-04). Three females from the northeast replication of clones were replaced (2 plants of 6-04 and 1 plant of 4-04).

By early November 1981, no additional plants had died since the replanting in mid-July. Survival for the entire orchard averaged 97.9 percent (table 1). Seedling and clone survival were still essentially the same, 98.1 percent and 97.7 percent respectively. Mortality in the clone replications was due entirely to the loss of females; all of the males were still alive.

By late August 1982, survival for the entire orchard averaged 94.7 percent (table 1). Cloned plants had slightly better survival than seedlings 95.0 percent and 94.4 percent respectively. This was the first year that the clones expressed a better survival rate than seedlings. This also was the first year that the clones experienced any male mortality. However, male survival was still better than female survival, 96.6 percent and 94.7 percent, respectively. Mortality in the clone replications was due primarily to the loss of three females (8 plants of 1-20, 5 plants of 8-56, and 4 plants of 6-04) and one male (3 plants of 5-15).

The winter temperatures of 1981-82 were extremely cold. Two periods (one in early January and another in early to mid-February) had minimum temperatures colder than -20° F (-28.9° C). This was probably one of the important factors contributing to the 1982 mortality in the orchard.

Sex Expression - Seedlings 1982

In late August 1982, the sex expression for the two replications of seedlings was: 43.0 percent female, 30.2 percent male, 11.8 percent bisexual or monoecious, 9.1 percent flowerless, and 5.8 percent dead. When the nonflowering and dead plants were omitted, the sex expression did not differ significantly from that predicted by McArthur (1977) of 55 percent female, 35 percent male, and 10 percent monoecious.

Sex Expression - Clones

No shifts in sex expression in the clonal material have occurred during the study period.

Height and Crown Growth, Reproduction and Vigor - 1982

Height and crown growth, reproduction, and vigor were compared for clones and seedlings in late August 1982. The southwest replication of clones

Table 1.--'Rincon' survival by years for seedlings and clones.[1]

	Survival rate		
	Fall 1980	Fall 1981	Fall 1982
	- - - -	Percent	- - - -
Seedling:			
NW replication	99.6	98.4	94.2
SE replication	98.4	97.7	94.6
Average	99.0	98.1	94.4
Clone:			
SW replication			
Male	100.0	100.0	93.2
Female	97.1	95.9	93.1
Average	97.6	96.6	93.1
NE replication			
Male	100.0	100.0	100.0
Female	99.0	98.6	96.2
Average	99.2	98.8	96.9
Average for clones: (both replications)	98.4	97.7	95.0
Average for orchard: (Seedling and clone)	98.7	97.9	94.7

[1]The orchard was planted in May 1980. In mid-July 1981, all dead plants (10 seedlings and 12 clones) were replaced. The 1981 and 1982 data also reflect the replaced plants.

was significantly shorter than the southeast replication of seedlings (table 2). The northeast replication of clones had significantly larger crowns than the southwest replication of clones or either replication of seedlings (table 2). Reproduction was significantly more abundant in the northeast replication of clones and northwest replication of seedlings. Vigor was not significantly different in any replication of seedling or clone plants (table 2).

Height, crown, reproduction, and vigor were apparently not significantly different between male and female clones, although males tended to be taller and females broader (table 3). Female clones were taller, broader, and more vigorous on average than female seedling plants.

Seed Production

Estimated seed production in 1981.--Seed production was first noted in the fall of 1981, a year and five months after planting. The seed was not harvested, but an estimation was made for each plant as to whether its seed production was heavy, moderate, light, or very light. Considering the entire orchard in the fall of 1981, a total of 446 plants (44 percent) were producing seed. This represented 264 plants in the two replications of clones and 182 plants in the two seedling replications. Each replication of seedlings had 91 plants producing seed.

Considering the clones, the southwest replication had 125 females, or 29.9 percent, producing seed. The northeast replication had 139 females, or 33.3 percent,producing seed. The difference between the seed production for the two replications of clones could be caused by the soil differences discussed earlier.

The estimated 1981 seed production for the clones was noted for each numbered female. Female 11-37 had a large number of females producing seed in 1981 and was also a good seed producer in 1982. However, number 1-01 had no plants producing seed in 1981, but was a good seed producer in 1982. A large number of plants of female 1-20 were producing seed in 1981, but this female was not considered a good seed producer in 1982. This indicates that the seed production from the cloned plants in the orchard has not been consistent for each female. The consistency may improve as the orchard matures.

Seed production in 1982.--In 1982 the seed production from the 'Rincon' orchard was hand-harvested. Harvesting started in late October and was completed on November 18. Based on the 36 man-hours required for harvesting the northeast replication of the clones (the heaviest seed producer), approximately 144 man-hours were required for harvesting the entire 3.1 acre (1.3 ha) orchard.

Utricles from the northeast replication of the clones were examined for fill and averaged 51.5 percent. A fill of 50 percent for a wild stand of fourwing saltbush is regarded as good (Gerard 1978).

Utricle fill was examined in relation to the position on the plant where the seed was found (table 4A). The position on the plant did not have a significant influence on utricle fill.

Table 2.--A comparison of height, crown, reproduction, and vigor by analysis of variance (all blocks) for both replications of clones and seedlings.

	Height	Crown	Reproduction[1]	Vigor[1]
	-- centimeters --			
Northeast clone	109.3 ab[2]	213.8 a	6.1 a	7.7 a
Southwest clone	106.7 b	188.9 c	5.0 b	7.6 a
Southeast seedling	111.2 a	203.7 b	4.6 b	8.0 a
Northwest seedling	108.5 ab	200.7 b	5.8 a	7.8 a

[1]Reproduction and vigor are numerical estimations where 1 is low and 9 is high.
[2]Values followed by the same letters are not significantly different ($P<0.05$) by the multiple range comparison tests.

However, the poorest fill was found on the north side of the plant, probably due to wind direction during pollination. Winds seldom blew from the north during pollination.

Utricle fill was also examined in relation to the distrance of the female from the male pollen-producing plants. Each numbered female was replicated three times, and the individual rows were spaced at different distances from the male (fig. 2). Distance of the female from the male did not have a significant influence on utricle fill (table 4B). This means that the orchard design was adequate for pollination.

Utricle fill was also evaluated in relation to the different numbered females. The female parent did have a significant effect on utricle fill (table 4C). Females 1-01 and 4-04 had the best fill. A good fill was also found for numbers 11-37 and 8-56. Female 1-20 had the poorest fill.

In 1982 a total of 363.7 pounds (165 kg) of clean seed was harvested from the 3.1 acre (1.3 ha) orchard (table 5). This averaged 117.3 lb per acre (131.5 kg/ha) of clean seed considering both replications of seedlings and clones.

The two replications of seedlings produced only 127.2 lb (57.7 kg) of clean seed, which represented only 35 percent of the total production for the entire orchard. The two replications of clones produced 236.5 lb (107.3 kg) of clean seed, and represented 65 percent of the seed production from the entire orchard. The northeast replication of the clones was the most productive with 144.3 lb (65.5 kg) of clean seed. It is interesting to note that each replication of clones produced more seed than either of the two replications of seedlings. Seed production in 1982 was significantly greater ($P<0.01$) for the clones than for the seedlings (table 6A). A comparison of seed production was made between the two replications of clones. Seed production was significantly

Table 3.--"T" test comparison of height, crown, reproduction, and vigor of male vs female cloned plants and of female clones vs female seedlings.

83 male vs 407 female clones				
	Male (83 clones)	Female (407 clones)	Significance[1]	Probability
Height (cm)	117.5	107.7	NS	0.05
Crown (cm)	195.0	202.7	NS	.10
Reproduction[2]	5.9	5.5	NS	.10
Vigor[2]	7.8	7.8	NS	.90

407 female clones vs 220 female seedlings			
	Clones (407 female)	Seedlings (220 female)	Significance
Height (cm)	110.6	107.7	*
Crown (cm)	210.5	202.7	*
Reproduction[2]	5.5	5.6	NS
Vigor[2]	8.1	7.8	*

[1]NS = Not significant, * = $P<.05$
[2]Reproduction and vigor are numerical estimations where 1 is low and 9 is high.

Table 4.--Percent seed fill evaluated by analysis of variance (with multiple range tests). Seed fill was evaluated in relation to position on the plant (A), distance from male (B), and different numbered females (C).

A

Seed fill by position on plant

Position	Top	East	South	West	North	Significance[1]
% Fill	60.4	52.4	50.6	48.0	38.0	NS

B

Seed fill by parent and row (distance from males)

Each female occurred three times in each replication of clones. This test was done to find out if there was a difference in fill within the three rows since they occurred at different distances from the male plants (fig. 2).

Female	$\bar{X}$	Range	F^{2}_{6}	Significance
1-01	72.8	68-81	1.4	NS
4-04	64.1	39-78	1.4	NS
11-37	56.6	43-70	.3	NS
8-56	55.6	42-69	1.1	NS
6-04	43.0	18-59	1.7	NS
1-20	16.7	0-39	2.9	NS

C

Seed fill for different numbered females

F = 33.6**

Number female	1-01	4-04	11-37	8-56	6-04	1-20
% fill	72.8	64.1	56.6	55.6	43.0	16.7

[1]NS = not significantly different, ** = P<0.01, lines under mean values indicate no significant difference.

greater in the northeast replication of clones (table 6B). This can probably be explained by the soil difference discussed earlier. Seed production for the two replications of seedlings was found to be not significantly different (table 6C).

Seed production per row (11 plants) in 1982 was examined by individual numbered female for the two replications of clones. The seed production from the two replications of clones was produced in large part by two of the six females, 11-37 and 1-01 (table 7). These two females accounted for 75 percent of the total seed production from the two replications of clones. Statistically, females 11-37 and 1-01 produced significantly more seed than the other females. Female plants of 1-20 produced the smallest amount of clean seed (table 7). We point out, however, that the orchard is still young and the other females may produce more later. It should be remembered that some plants were producing only for the first year in 1982 whereas others had produced for 2 years. Furthermore, to maintain a broader genetic base, all females should be included in the orchard. Selection of female plants was based on forage production, tendency to be evergreen, and growth form, as well as seed production.

Table 5.--Clean seed weights for seedlings and clones in 1982.

Type of Seed	Weight (Pounds)	Pounds per acre
Seedling:		
Northwest replication	72.6	
Southeast replication	54.6	
Total	127.2	82.1
Clone:		
Southwest replication	92.2	
Northeast replication	144.3	
Total	236.5	152.6
Total for orchard	363.7	117.3

Table 6.--X^2 analyses of seed production, 1982. A comparison of clones and seedlings-A, two replications of clones, northeast vs southwest-B, two replications of seedlings, northwest vs southeast-C.

		Observed	Expected
A.	Clones	236.5	181.8
	Seedlings	127.2	181.8
		$X^2 = 32.8$, DF = 1, $P \ll 0.01$	
B.	Northeast clones	144.3	121.8
	Southwest clones	99.2	121.8
		$X^2 = 8.3$, DF = 1, $P < .01$	
C.	Northwest seedlings	72.6	63.6
	Southeast seedlings	54.6	63.6
		$X^2 = 2.5$, DF = 1, $.3 > P > .2$ (NS)	

Table 7.--Seed production per row (11 plants) for clones in 1982. Seed production is listed by numbered females for each replication.

Numbered female	Southwest replication	Northeast replication
11-37	[1]14.3 a	[1]18.4 a
1-01	10.0 b	16.3 a
6-04	3.6 c	5.7 b
8-56	1.3 d	2.8 c
4-04	0.6 de	2.0 cd
1-20	0.4 e	0.8 d

[1]Letter differences signify mean differences at P<0.05. Bartlett's test for homogeneity of variances did not allow combining of blocks.

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Section 6. Animal Relationships

POTENTIAL USE OF FOURWING SALTBUSH AND OTHER DRYLAND SHRUBS FOR UPLAND GAME BIRD COVER IN SOUTHERN IDAHO

Nancy Shaw, Alan Sands and Dale Turnipseed

ABSTRACT: Twenty-nine accessions of fourwing saltbush (Atriplex canescens [Pursh] Nutt.) were transplanted on a semiarid southern Idaho site to determine adaptability, and to evaluate which accessions best met upland game cover criteria. A cover index value was computed for each shrub. All accesssions of fourwing saltbush appeared to be well adapted to the site; structural characteristics varied widely. Growth rates and habits of fourwing saltbush, big sagebrush (Artemisia tridentata Nutt.), silver sagebrush (A. cana Pursh), winterfat (Ceratoides lanata [Pursh] J.T. Howell), rubber rabbitbrush (Chrysothamnus nauseosus [Pallas] Britt.), and forage kochia (Kochia prostrata [L.] Schrad.) were also compared. Use of these shrubs provides an opportunity to increase vertical stratification to meet the various cover needs of upland game birds.

INTRODUCTION

Ring-necked pheasants (Phasianus colchicus L.), California quail (Callipepla californica Shaw), and gray partridge (Perdix perdix L.) are common upland game birds associated with irrigated agricultural lands in southern Idaho. The recreation and esthetic values provided by these birds are substantial. Statewide, pheasant hunting alone accounts for an estimated 500,000 hunter-days annually, most of which occur in southern Idaho (Idaho Department of Fish and Game 1983).

The habitat needs of these birds are not entirely fulfilled by croplands. Farming practices are intensive; fence rows and other waste areas are cleared of natural vegetation, and fields are frequently fallow during fall and winter. Consequently, unfarmed habitats are crucial to upland game birds at certain times of the day and season. Shrub/grass habitats are particularly attractive to quail and pheasants. Shrubs are the focal point of all California quail activity (Leopold 1977). Pheasants use shrub-covered areas intensively during the fall and winter (Salinger 1950; Swanson and Yocum 1958; Hansen and Labisky 1974; Morton 1971; Gates and Hale 1974; Snyder 1982). Early pheasant nesting frequently occurs in shrub-grass cover types (Bartmann 1969; Gates and Hale 1975). Shrub cover is considered relatively unimportant to gray partridge, but they are often associated with shrubs during severe weather (Weigand 1980; Mendel and Peterson 1983).

Although it is widely understood that wildlife respond to the structural features of their environment, little work has been done to describe the physical characteristics of individual shrubs used by pheasants and quail. It is generally believed that shrubs that are low growing (2 to 8 feet [0.6 to 2.4 m] in height), broadly crowned, and densely branched with lateral branches close to the ground provide better cover (thermal and hiding) than upright, sparsely branched shrubs (Leopold 1977; Adkins 1980).

Fourwing saltbush (Atriplex canescens [Pursh] Nutt.) has been studied since 1964 as an upland game cover plant, and promoted for that use since 1968 (California Department of Fish and Game 1968; McKibben and Slayback 1977; California Department of Fish and Game and USDA Soil Conservation Service 1980). Fourwing saltbush is adapted to arid sites, occurs over an extensive region, develops rapidly from seed or transplants, and can be planted with other species (Plummer and others 1966; Van Epps and McKell 1977). It has shown considerable interaccessional variation in a number of characteristics including size, growth rate, and growth form (Plummer and others 1966; Stutz and others 1975; McArthur and others 1983). Fourwing saltbush has also been found to significantly increase the production of grass growing in association with shrubs (Rumbaugh and others 1982), a situation which may enhance nesting cover for pheasants (Wood and Brotherson 1981).

We evaluated the structural characteristics of 29 accessions of fourwing saltbush (table 1) at a site in Twin Falls County, Idaho, to determine which best met upland bird winter cover criteria. We also compared differences in growth rates and growth habits of selected fourwing saltbush accessions, other introduced shrub species and accessions, and native Wyoming big sagebrush (Artemisia tridentata Nutt. ssp. wyomingensis Beetle and Young) at this site (table 2). Shrub accessions originated from seed collected from native stands in seven western states (fig. 1).

Shrub selection trials are part of a cooperative program between the USDI Bureau of Land Management, Idaho Department of Fish and Game, and the USDA Forest Service, Intermountain Forest and Range Experiment Station, to enhance wildlife habitat on public lands in Idaho.

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Table 1.--Location of native stands of fourwing saltbush accessions grown at Bell Rapids site.

Accession	Elevation	Latitude	Vegetation type
	Ft	° N	
Black Mtn., Sevier County, UT	6,230	38°50'	Pinyon-juniper, sagebrush
Tuba City, Coconino County, AZ	4,990	36°08'	Fourwing saltbush
St. George, Washington County, UT	2,760	37°06'	Fourwing saltbush
Hanksville, Wayne County, UT	4,300	38°23'	Shadscale, greasewood
Ephraim, Sanpete County, UT	5,510	39°22'	Fourwing saltbush, greasewood
Emery, Emery County, UT	6,200	38°54'	Gardner saltbush, fourwing saltbush
Reno, Washoe County, NV	4,490	38°31'	Fourwing saltbush, shadscale
Delta, Delta County, CO	4,990	38°40'	Fourwing saltbush
Keams Canyon, Navajo County, AZ	6,300	35°50'	Basin big sagebrush, fourwing saltbush
Rincon Blanco, Rio Arriba County, NM	7,870	36°30'	Pinyon-juniper
Escalante, Garfield County, UT	5,810	37°44'	Fourwing saltbush
Randlett, Uintah County, UT	4,790	40°12'	Fourwing saltbush
Pine Valley, Washington County, UT	5,300	38°41'	Pinyon-juniper
Lund, Iron County, UT	5,080	38°02'	Fourwing saltbush, greasewood
Fayette, Sanpete County, UT	5,050	39°14'	Pinyon-juniper
Grand Junction, Mesa County, CO	4,590	39°05'	Fourwing saltbush
Reynolds Creek, Owyhee County, ID	4,000	43°16'	Fourwing saltbush, Wyoming big sagebrush
Timpanogas, Wasatch County, UT	6,000	40°22'	Fourwing saltbush, mountain big sagebrush
Kanab, Kane County, UT	4,990	37°02'	Fourwing saltbush
Cedar City, Iron County, UT	5,810	34°40'	Pinyon-juniper
San Rafael Swell, Emery County, UT	5,710	39°00'	Pinyon-juniper
Desert Range Experiment Station, Millard County, UT	5,310	38°37'	Shadscale, greasewood
Gunnison, Gunnison County, CO	7,680	38°32'	Shadscale, fourwing saltbush
Manila, Daggett County, UT	6,820	41°00'	Pinyon-juniper, mountain big sagebrush
Panaca, Lincoln County, NV	4,660	37°40'	Northern desert shrubs
Huntington, Emery County, UT	5,900	39°20'	Pinyon-juniper
Jackson Springs, Washington County, UT	5,080	37°24'	Pinyon-juniper
Bliss, Gooding County, ID	3,260	42°56'	Basin big sagebrush, fourwing saltbush
Jericho, Juab County, UT	5,248	39°40'	Fourwing saltbush

Table 2.--Performance of six shrub accessions at Bell Rapids study site.[1]

Species/Accession	Elevation	Latitude	Vegetation type	Survival	Height	Crown
	Ft	° N		Percent	---Inches---	
Artemisia cana Pursh. ssp. cana. Decker, Bighorn County, Mont.	3,510	44°58'	Silver sagebrush, fourwing saltbush	95	25	47
Artemisia tridentata Nutt. ssp. vaseyana (Rydb.) B. Boi. Carey, Blaine County, Idaho	4,790	43°19'	Mountain big sagebrush	93	34	29
Artemisia tridentata Nutt. ssp. wyomingensis Beetle and Young. Bell Rapids, Twin Falls County, Idaho[2]	3,080	42°41'	Wyoming big sagebrush	--	15	14
Ceratoides lanata (Pursh) J.T. Howell. Hatch, Garfield County, Utah	6,990	37°38'	Mountain big sagebrush	70	22	35
Chrysothamnus nauseosus (Pallas) Britt. ssp. albicaulis (Nutt.) Rydb. Marysvale, Piute County, Utah	5,840	38°28'	Wyoming big sagebrush	60	34	41
Chrysothamnus viscidiflorus (Hook.) Nutt. ssp. lanceolatus (Nutt.) Greene. Decker, Bighorn County, Mont.	3,510	45°01'	Silver sagebrush, Wyoming big sagebrush	26	13	20

[1] Survival and growth of transplanted accessions sampled following fifth growing season.
[2] Native stand of mature plants.

Figure 1.--Map showing original collection sites of fourwing saltbush and other shrub accessions grown at Bell Rapids site.

STUDY AREA

The Bell Rapids study area is located on the Snake River Plains approximately 13 miles (21 km) northwest of Buhl in Twin Falls County, Idaho. Topography of the area is undulating. Elevation is 3,440 feet (1 050 m). The fine-silty to fine-loamy soils are well drained and approximately 60 inches (152 cm) deep with a lime silica cemented duripan at 34 to 40 inches (86 to 102 cm). Prior to disturbance, the area was representative of the Wyoming big sagebrush/thurber needlegrass (Stipa thurberiana [Piper in Scribn.]) habitat type (Hironaka and others 1983). Most of the area has been converted to irrigated agricultural land. Scattered tracts of public land represent the only unfarmed habitats in the area. Vegetation on these tracts is currently dominated by Wyoming big sagebrush/cheatgrass (Bromus tectorum L.), cheatgrass, or crested wheatgrass (Agropyron cristatum [L.] Gaertn.).

Climate of the area is semiarid. Average annual precipitation is estimated at 9.1 inches (23 cm), based on the long-term average at Bliss, Idaho, 13 miles (21 km) north of the study site. During the 1978-83 study period, annual precipitation averaged 10.2 inches (26 cm). Approximately 35 percent of the precipitation occurs between April 1 and September 31. The frost-free season averages 148 days. From 1978 to 1983 the average minimum daily temperature in January was 20.5° F (-6.4° C) while the lowest recorded temperature during this period was -14.0° F (-25.8° C). Winter snow cover is normally light and intermittent.

METHODS

Utricles of fourwing saltbush were dewinged, clipped, leached in running water, and stratified for 2 weeks. Seedlings were propagated in Leach tubes. Four or five utricles were planted in each tube and seedlings were thinned to one per tube after the first secondary leaves developed. After 10 weeks of growth, seedlings were hardened off by gradually increasing their exposure to ambient conditions.

Field sites were cleared of vegetation and tilled prior to planting. Seedlings were transplanted in March 1978. The fourwing planting site was divided into four blocks which were subdivided into row plots. Ten seedlings of each accession were planted in a randomly selected row plot in each block. Seedlings of some accessions were planted in only two or three row plots when propagation problems or a lack of seed limited the number of transplants produced. Seedlings were planted on 6 foot (1.8 m) centers. Additional shrub species and accessions were also propagated and transplanted in a similar manner. These were transplanted adjacent to the fourwing saltbush planting or at one of two additional planting sites located within a 3-mile (4.6-km) radius. Hand and mechanical weeding were employed to reduce competition during the first 2 years following transplanting.

Winter cover characteristics provided by the 29 fourwing saltbush accessions and native Wyoming big sagebrush were evaluated in February 1983. Parameters sampled were: survival; height; crown spread; growth type (0=erect, 1=semierect, 2=diffuse); growth form (0=open treelike canopy, 1=many branches, canopy somewhat open, 2=closed canopy, dense branches); leaf retention (0=none to poor, 4=excellent); and seed retention (0=none to poor, 4=excellent). Each surviving fourwing saltbush shrub was sampled. Wyoming big sagebrush data were obtained from 40 mature plants selected randomly from a native stand adjacent to the fourwing saltbush plots.

A cover index value was also computed for each shrub. The parameters judged to contribute substantially to the quality of cover provided by individual shrubs were given weighted values (crown diameter=20 percent, growth type=30 percent, growth form=30 percent, leaf retention= 20 percent). The following formula was used:

$$\text{Cover Index} = \frac{\text{crown diameter (inches)}}{78.4} \times 20 + \frac{\text{growth type score}}{3} \times 30 + \frac{\text{growth form score}}{3} \times 30 + \frac{\text{leaf retention score}}{4} \times 20.$$

Plants with high scores for each parameter received scores approaching 100. Plants greater than 78.4 inches (200 cm) in crown diameter could attain cover index scores greater than 100, provided the other values were at or near maximum. Height was not included in the index as all accessions were considered to provide adequate vertical cover. Seed retention is reported separately from the cover index values for each accession as the plants are dioecious. High seed retention was judged to significantly improve the quality of cover provided by female plants in winter and should be considered with the cover index in evaluating individual accessions.

Means of all parameters sampled were computed for each accession. Height, crown, and cover index values were analyzed using analysis of variance techniques. Mean separations for cover index values were performed with the Duncan Multiple Range Test (Steele and Torrie 1960). Growth rates of the fourwing saltbush and other shrub accessions were derived from annual maximum height and crown measurements of each shrub. Data were recorded annually, beginning in 1978 in late summer when vegetative growth had diminished.

RESULTS

Fourwing Saltbush Accessions

Fourwing saltbush appears to be well adapted to the Bell Rapids site. Plants of all accessions are vigorous, and little mortality has occurred since the first growing season following transplanting (table 3). There were significant ($P < 0.05$) differences among accessions in height, crown, and cover index values. No accession exhibited consistently high scores in all categories, although the Black Mountain, Sevier County, Utah, and Tuba City, Coconino County, Arizona, accessions did score strongly in all traits and received the highest cover index values.

The Rincon Blanco, Rio Arriba County, New Mexico, accession ranked highest in combined leaf and seed retention. This accession is from the parent material used to develop the 'Rincon' fourwing selection recently released for commercial production by the USDA Soil Conservation Service and cooperating agencies (McArthur and others 1982). It is likely that the 'Rincon' selection would score higher as an upland game bird cover plant than the parent stock. The 'Rincon' selection generally is less erect, has more foliage, and produces more seed than the parent stock (McArthur and others 1983).

The very open growth form of the gigas diploid Jericho accession, Juab County, Utah, contributed to its low cover index value. Mean height of this accession was greater than that of any other accession. Large size and open growth are characteristic of this accession on its native site and in other common gardens (Stutz and others 1975; McArthur and others 1983).

Table 3.--Cover characteristics of 29 accessions of fourwing saltbush and native Wyoming big sagebrush at Bell Rapids.

Accession	N[1]	Survival	Height	Crown	Growth type[2]	Growth form[3]	Leaf retention[4]	Seed retention[4]	Cover index[5]
		Percent	--Inches--						
Fourwing saltbush									
Black Mountain	12	60	39	84	1.8	1.4	2.9	2.3	84.7 ± 23.4[a]
Tuba City	21	53	42	77	1.9	1.4	3.1	1.7	84.6 ± 15.2[a]
St. George	6	75	42	69	1.2	2.0	3.5	2.7	82.6 ± 9.6[ab]
Hanksville	12	60	35	69	2.0	0.9	3.6	2.0	79.3 ± 7.5[ab]
Ephraim	11	55	38	71	1.9	1.1	3.0	1.8	78.0 ± 19.5[abc]
Emery	16	67	37	74	1.6	1.1	3.6	1.8	72.9 ± 21.0[abc]
Reno	11	55	31	54	1.8	1.4	3.3	1.0	77.9 ± 14.5[abc]
Delta	24	80	39	73	1.9	1.0	3.0	1.5	77.2 ± 11.6[abcd]
Keams Canyon	14	70	35	63	1.7	1.0	3.4	2.0	73.5 ± 10.0[abcde]
Rincon Blanco	6	75	41	68	1.7	1.0	3.0	3.5	72.2 ± 16.4[abcde]
Escalante	27	75	31	63	1.9	1.0	2.4	1.5	72.1 ± 16.0[abcde]
Randlett	22	73	40	67	1.5	1.1	3.4	1.5	71.7 ± 21.8[abcde]
Pine Valley	22	56	30	63	1.4	1.2	3.1	2.7	71.1 ± 18.6[bcde]
Lund	30	77	30	52	1.6	1.1	3.3	1.5	70.5 ± 14.7[bcdef]
Fayette	26	72	35	65	1.8	1.0	2.5	1.3	70.2 ± 18.6[bcdef]
Grand Junction	12	71	46	77	1.6	0.8	3.0	2.0	69.6 ± 15.9[bcdefg]
Reynolds Creek	9	60	34	63	1.9	1.1	1.7	1.9	69.4 ± 18.3[bcdefg]
Timpanogas	30	75	36	65	1.7	0.9	2.3	1.4	68.2 ± 14.3[bcdefg]
Kanab	20	71	39	64	1.5	0.9	3.0	1.8	68.0 ± 22.3[bcdefg]
Cedar City	23	64	38	62	1.6	1.0	2.9	2.0	68.0 ± 15.7[bcdefg]
San Rafael Swell	19	53	35	68	1.6	0.9	2.7	1.9	67.9 ± 18.2[bcdefg]
Desert Range Experiment Station	14	78	34	63	1.6	0.9	2.9	1.6	67.8 ± 16.2[bcdefg]
Gunnison	26	65	33	54	1.8	0.8	2.7	1.3	66.5 ± 11.7[bcdefg]
Manila	14	39	41	63	1.6	0.9	2.7	0.9	65.9 ± 10.6[bcdefg]
Panaca	24	80	35	68	1.6	0.9	2.7	1.9	62.4 ± 18.2[efg]
Huntington	27	74	43	70	1.3	0.4	2.9	1.3	57.0 ± 7.5[fg]
Jackson Springs	16	80	39	78	1.8	1.0	3.4	2.2	56.5 ± 20.0[g]

Con.

Table 3. Con.

Accession	N[1]	Survival	Height	Crown	Growth type[2]	Growth form[3]	Leaf retention[4]	Seed retention[4]	Cover index[5]
		Percent	--Inches--						
Fourwing saltbush (con.)									
Bliss	38	95	32	65	1.1	0.1	2.3	2.3	45.3 ± 8.4[h]
Jericho	7	78	54	74	0.9	0.4	2.1	2.8	38.9 ± 27.9[i]
Wyoming big sagebrush									
Bell Rapids	40	--	14	15	0.2	1.4	1.1	0.0	33.7 ± 9.2

[1] N = number of surviving plants.
[2] Growth type (0=erect, 1=semi erect, 2=diffuse).
[3] Growth form (0=open treelike canopy; 1=canopy somewhat open, many branches; 2=closed canopy, dense branches).
[4] Leaf or seed retention (0=none to poor, 1=poor, 2=fair, 3=good, 4=excellent).
[5] Mean cover index ± standard deviation. Means followed by the same letter superscript are not significantly different at $P<0.05$ level of significance using Duncan's multiple range test.

The Bliss accession, Gooding County, Idaho, collected from cliffs on the north bank of the Snake River approximately 10 miles (16 km) east of the study site, exhibited excellent survival, but received a low cover index rating due to its open canopy and moderate crown size. Other native populations of fourwing saltbush possessing more desirable cover characteristics have been identified growing on the floodplain of the Snake River in the Bell Rapids area.

Within accessions, individual plants frequently differed in cover characteristics, reflecting the inherent variation within the species. Similar variation would be expected in cover plantings produced from seed. Cover quality and plant uniformity might be increased by collecting seed only from selected plants with desirable cover characteristics. Variation would still be expected because the shrubs are open pollinated. Cover quality might be more reliably increased by establishing plantings from rooted cuttings taken from plants with high cover index values. Techniques for the propagation of fourwing saltbush from cuttings are described by Wiesner and Johnson (1977). In addition, the ratio of female to male plants can be regulated by this method to maximize the number of seed-producing plants (McArthur and others 1978).

Other Shrubs

Although low mean annual precipitation limits the number of species that can be selected to provide wildlife cover on nonirrigated lands in southern Idaho, several species have exhibited good survival (table 2) and vigor when grown in species selection plots at the Bell Rapids site. Not all of these species would provide winter cover for upland game birds. They could be included in plantings to increase the diversity of plants and vertical stratification of the vegetation to meet other habitat needs of upland game birds and to provide perching and nesting habitat for other bird species.

The white rubber rabbitbrush (Chrysothamnus nauseosus [Pallas] Britt. ssp. albicaulis [Nutt.] Rydb.) accession consists of relatively large shrubs with an open, erect growth habit. They do not retain seed or leaves through the winter. The accession does provide height which is lacking in the native Wyoming big sagebrush. Survival and vigor of the mountain rubber rabbitbrush (Chrysothamnus viscidiflorus [Hook] Nutt. ssp. lanceolatus [Nutt.] Greene) accession is low, indicating poor adaptability to the site.

The winterfat (Ceratoides lanata [Pursh] J.T. Howell) accession is a foothill variety from Hatch, Garfield County, Utah. Its mean height at the Bell Rapids site is 22 inches (56 cm). Growth habit is open and spreading, but grass tends to grow within and around the crown of the plant, possibly increasing its value as nesting cover.

Wyoming big sagebrush received a lower cover index value than any fourwing accession rated (table 3). Its mean crown diameter was smaller than any species or accession examined (fig. 2). Nevertheless, when cover is limited on adjacent agricultural habitats, Wyoming big sagebrush/grass habitats are used intensively by pheasants during the winter in southern Idaho. It is our opinion that this type of habitat provides adequate daytime hiding cover but a fourwing/grass habitat would be superior in moderating the effects of severe weather and would be selected by pheasants during adverse conditions. We do not advocate the

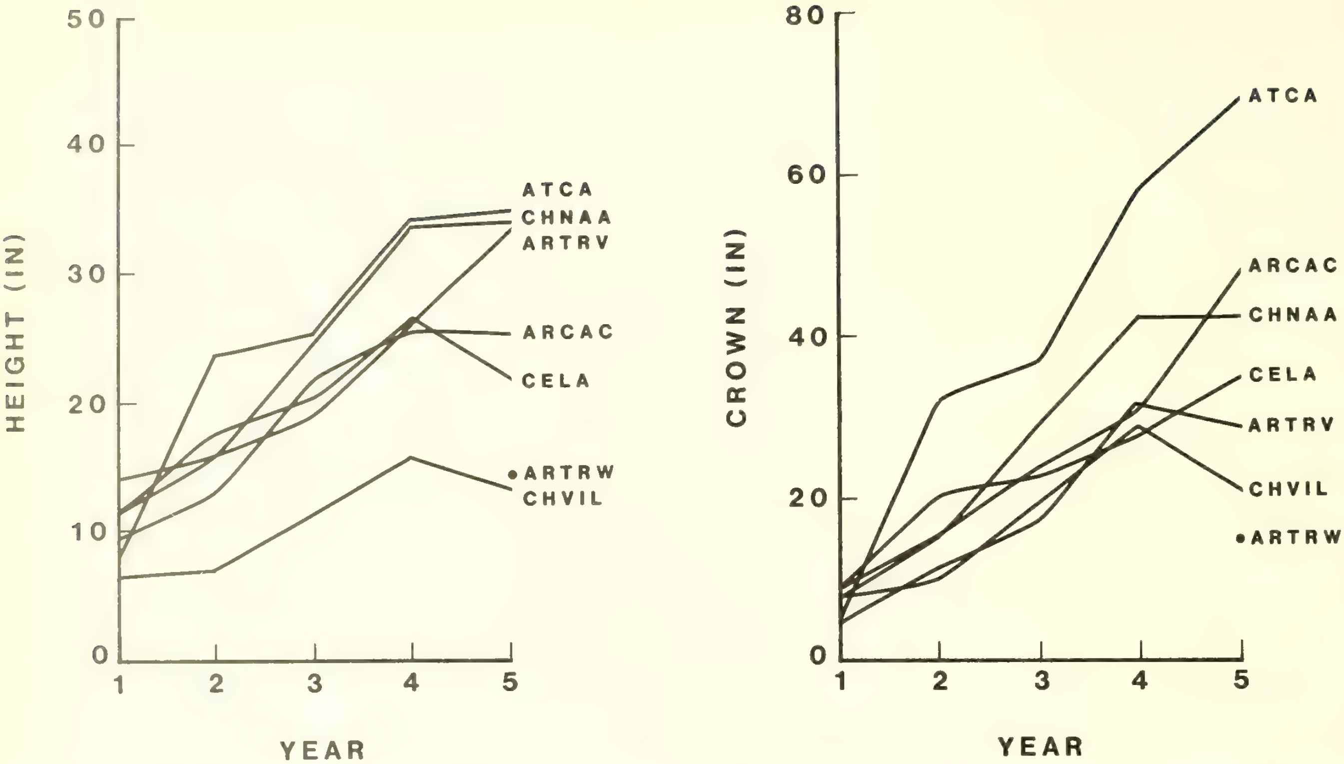

Figure 2.-- Height and crown development of selected shrub accessions at Bell Rapids. Fourwing saltbush data are means for accessions 1 through 12 (table 1). Remaining accessions are identified in table 2. ARCAC=Artemisia cana cana, ARTRV=Artemisia tridentata vaseyana, ARTRW=Artemisia tridentata wyomingensis[1], ATCA=Atriplex canescens, CELA=Ceratoides lanata, CHNAA=Chrysothamnus nauseosus albicaulis, CHVIL= Chrysothamnus viscidiflorus lanceolatus.

[1]Only mature plants were measured.

removal of native sagebrush stands to plant fourwing or other shrubs until comparative use evaluations indicate that other shrubs are clearly superior to native sagebrush as upland game cover. Present efforts are directed toward the enhancement of cover on depleted shrublands.

Mountain big sagebrush (Artemisia tridentata Nutt. ssp. vaseyana [Rydb.] B. Boi.), and silver sagebrush (A. cana Pursh ssp. cana) did not receive cover index ratings. They would have likely scored higher than the Wyoming big sagebrush based on their crown development (fig. 2) and ocular assessment. Survival (table 2) and growth rates (fig. 2) of both species were very good in spite of the significant differences between their native sites and the study area. The ability of silver sagebrush to sprout after fire (Beetle 1960) increases its potential utility as an upland game bird cover plant.

Height and crown development for each of these shrub species and a composite of the 12 highest ranking fourwing saltbush accessions are illustrated in fig. 2. Following the second growing season, the mean crown diameter of the 12 fourwing saltbush accessions was about 65 percent greater than that of any of the other shrub accessions. After 5 years, this figure had dropped to about 55 percent. None of the other shrubs tested or the native Wyoming big sagebrush provide the combination of crown diameter, dense canopy cover, and rapid growth as did the fourwing saltbush accessions. The production of significant amounts of cover following two growing seasons make fourwing saltbush particularly valuable as a cover plant on burns, waste areas, or disturbed sites.

An additional shrub, forage kochia (Kochia prostrata [L.] Schrad.) has received limited testing at the Bell Rapids site. This shrub provides dense, low growing cover, similar to that provided by alfalfa. However, it retains its structure better through the winter and spring months. It may have significant value as a pheasant nesting cover plant.

CONCLUSIONS

A variety of accessions of fourwing saltbush are well adapted to the semiarid lands in southern Idaho. They readily established from transplanting without irrigation and grew rapidly. Populations may be selected that provide a dense,

heavily branched canopy and tend to retain their seeds and leaves late into the winter. Local seed sources or sources from higher elevations are recommended (Van Epps 1975; McArthur and others 1983). Mixed plantings of fourwing saltbush, big sagebrush, silver sagebrush, white rubber rabbitbrush, winterfat, forage kochia, and grasses provide an opportunity to diversify upland game bird cover without irrigation. These plantings can provide important habitat for upland game birds and other wildlife when cover is lacking on adjacent irrigated agricultural lands.

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POTENTIAL OF ATRIPLEX AND OTHER CHENOPOD SHRUBS FOR INCREASING RANGE PRODUCTIVITY AND FALL AND WINTER GRAZING USE

R.M. Ostyina, C.M. McKell, J.M. Malecheck, and G.A. Van Epps

ABSTRACT: There has been an increasing awareness of the value of shrubs in forage production and for revegetation of disturbed lands. Forage value is probably highest during fall and winter periods in cold desert ecosystems. Several Chenopodiaceae species have been analyzed for browse productivity and nutritive quality for livestock use. Atriplex canescens (Pursh) Nutt., Kochia prostrate (L.) Schrad., and Ceratoides lanata (Pursh) J.T. Howell, are highly productive and nutritious in mixes with Agropyron desertorum (Fisch.) Schult. These shrubs can significantly improve crude protein content and in vitro dry matter digestibility of sheep forage in the fall and early winter.

INTRODUCTION

Shrubs are a neglected resource for forage production in many parts of the world. Misconceptions of their value have hindered objective appraisals of shrubs. Shrubs are often considered weedy invaders, unpalatable to livestock, and low in feed value (McKell 1975).

Recently, shrubs have received increased interest as livestock forage and valuable revegetation species on disturbed lands, especially in arid regions. Their potential is being evaluated in many parts of the world, including the United States, Africa, Australia, and the Middle East. Several shrub species have been analyzed for productivity, chemical composition, palatability, and preference by grazing animals (Wilson 1969; Le Houreou 1980). Selection of superior shrubs, planting them in favorable sites, and using appropriate management practices, could improve arid ranges for animal production. However, management and integration of shrubs into grazing systems requires considerably more information than is presently available. The purpose of this paper is to review some of the major features of three chenopod shrubs in relation to their value for improving rangeland productvity and utilization.

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SHRUBS ON SEEDED RANGELANDS

Several thousand hectares of rangelands in the Intermountain region were planted to crested wheatgrass (Agropyron desertorum [Fisch.] Schult.) and Agropyron cristatum (L.) Gaertn.) in the 1940's and 50's. However, little attention was given to seeding forbs and shrubs. These monospecific seedings are used to provide grazing for livestock during the spring, summer, and fall (Frischknecht 1968). Some seeded foothill ranges are also used in late fall and early winter by livestock with or without supplementation (Kearl and others 1971; Cook and Harris 1968).

After late summer, most cool season grasses become dormant and their protein content declines below livestock condition maintenance needs while livestock protein needs remain high. Cook and Harris (1968) reported that mature grass forage is too low in protein to meet livestock gestation requirements. However, during this same time shrubs are high in protein, but are decidedly low in energy sources. Among the many shrubs found around the world, the family Chenopodiaceae has many genera adapted to arid and saline regions. Some of the genera with forage potential are: Atriplex, Kochia, and Ceratoides.

Fourwing Saltbush

Fourwing saltbush, (Atriplex canescens [Pursh.], Nutt.) a dioecious shrub, occurs widely on desert and foothill ranges in the Western United States. In Utah it produces abundant and nutritious forage as well as seeds. Fourwing saltbush is very drought resistant, survives and grows well on dry sites, and tolerates considerable alkalinity (Plummer and others 1966; Blauer and others 1975). According to Sampson and Jesperson (1963), fourwing saltbush rated good to fair as a browse for sheep, goats, and deer, and fair to poor for cattle and horses. Fourwing saltbush is easily established from seeds and cuttings and plants persist well in association with other shrubs and grasses. Monsen (1980) reported successful interseeding of fourwing saltbush and crested wheatgrass onto southern Idaho rangelands dominated by sagebrush.

Prostrate Kochia

Prostrate kochia (Kochia prostrata [L.] Shrad.) was introduced into the United States from Asia. It is a valuable shrub for browse in the USSR where it is utilized by both domestic livestock and wildlife (Shishkin 1936). Prostrate kochia is well adapted to dry western ranges and does well on neutral, saline, and even alkaline soils

(McArthur and others 1974). Productivity for this small chenopod is high according to Plummer and others (1970) who reported 1584 lb/acre (1,800 ka/ha) of dried herbage the year it was introduced to Utah. Balyan (1972) reported yields of 27.3 - 31.8 tons/acre (30-35 tons/ha) in pure stands in Russia.

Prostrate kochia belongs in the family Chenopodiaceae where some species, such as Halogeton glomeratus C.A. Mey, are known to cause oxalate poisoning in livestock (James and others 1967). In a study of forage quality, Davis (1979) indicated that oxalate levels in Kochia are lower than in fourwing saltbush and winterfat (table 1).

The tannin level (table 1) in prostrate kochia as well as in fourwing saltbush and winterfat is well below the critical level of 15 mg/g for livestock (Donnelly and Anthony 1969). The crude protein content of prostrate kochia (8.9-14.7 percent) is similar to that of fourwing saltbush (11.4-13.6 percent) and winterfat (10.1-16.8 percent) from August to March (Davis 1979).

Winterfat

Winterfat (Ceratoides lanata [Pursh.]J.T. Howell) is a subshrub that shows wide variations in stature. Dwarf forms may be less than 12 inches (30 cm) in height; robust forms grow up to 30 inches (75 cm). Winterfat is highly nutritious and palatable winter browse for livestock and big game. It is completely grazable except for the woody base and larger stems (Stevens and others 1977). As a result, even though it is relatively tolerant to grazing use, overgrazing has greatly reduced and even eliminated winterfat on some areas of the Intermountain region (Blauer and others 1975). Winterfat is potentially one of the most useful shrubs for range improvement and forage production on alkaline soils of the desert ranges in Utah and adjourning states where annual precipitation is less than 10 inches (25 cm).

Available literature on chenopods such as fourwing saltbush, prostrate kochia, and winterfat suggests that these shrubs exhibit considerable promise as natural supplements to crested wheatgrass for fall-winter grazing. Planting these shrubs in existing grass pastures could increase the use of mature grass forage that would otherwise not be grazed.

BIOMASS PRODUCTION

Chenopod shrubs on most arid lands throughout the world produce considerable amounts of biomass. Atriplex species grown under minimal cultural treatments can produce large amounts of forage. A study in Riverside, Calif. in 1969 showed that Atriplex polycarpa[Torr.] S. Wats., A. lentiformis [Torr.] S. Wats and A. canescens under minimal agronomic management could produce from 6679 to 8949 lb/acre (7 590 to 10 169 kg/ha) of herbage from closely spaced plants (Goodin and McKell 1971). Yields for fourwing saltbush ranged from 5195 to 5379 lb/acre (5 903 to 6 113 kg/ha) from low to high irrigation and compared favorably to alfalfa yields which were 5063 to 5861 lb/acre (5 753 to 6 660 kg/ha) (Goodin 1979).

In a seed pasture, fourwing saltbush produced 1.3 lbs (472 g) per plant at the Nephi Dryland Experiment Station in central Utah (Otsyina and others 1982). Atriplex size and productivity, however, depend greatly on both genetic and environmental factors. Recent studies at the USDA Forest Service Shrub Sciences Laboratory in Utah indicate that diploid Atriplex genotypes are more productive than tetraploid genotypes . Large differences among Atriplex ecotypes were shown in a study at the Nephi Station where ecotypes collected from nine different sites in the Intermountain region were grown in a uniform garden for 4 years under minimum cultural management (Van Epps and others 1982). Atriplex productivity averaged 8634 lb/acre (9 811 kg/ha), but highly significant differences existed among ecotypes.

The shrub biomass available for grazing is often difficult to estimate because the palatable new growth is protected by stout stems within the dense, compact growth form. Observations of sheep grazing on shrub species indicate that about two-thirds of the total current year's biomass is available as browse (Otsyina 1983).

Table 1.--Crude protein, crude fiber, tannins, oxalate, and carotene content of Kochia prostrata, Atriplex canescens, and Ceratoides lanata in November (Davis 1979).

Species	Crude protein	Crude fiber	Tannins	Oxalates	Carotene
	Percent	Percent	mg/g	Percent	mg/100g
K. prostrata	9.2	33.6	5.7	1.4	16.7
A. canescens	10.4	22.6	5.8	1.9	31.1
C. lanata	10.4	29.0	6.9	1.7	24.1

Productivity data for prostrate kochia are very scarce. Small pasture studies at the Nephi Station with prostrate kochia in combination with crested wheatgrass and other shrubs show that it is highly productive, 914 lb/acre (1 040 kg/ha) in a mix with crested wheatgrass. It contributed over 35 percent of the total available browse in the mixed pastures.

COMPETITION AND PERSISTENCE

Highest benefits from shrubs probably could be realized in mixtures with mature grasses. To contribute effectively, shrubs must be able to compete well with the grasses without detrimental effects on either component. Recent studies indicate that some chenopods are highly competitive in mixed stands. Rumbaugh and others (1982) examined forage quality and quantity in a pasture planted with various combinations of fourwing saltbush, grass, and legumes. They reported significant increases in forage yield when crested wheatgrass was grown with fourwing saltbush or legumes (Astragalus cicer L., Astragalus falcatus Lam. and Medicago sativa L.). The shrub and legume species not only contributed to an increase in production, but also stimulated the growth of crested wheatgrass. Less optimistic observations were reported by Monsen (1980) who noted that the presence of saltbush did not reduce grass density or herbage yields in Idaho.

Rumbaugh and others (1982) hypothesized that the increased forage yield in the grass/shrub mixtures may be attributed to nitrogen and mineral accumulation under the shrubs. Such a pattern was reported by Fairchild and Brotherson (1980) who found greater mineral concentrations under fourwing saltbush than under five other shrub species. Similarly, Charley (1977) and Charley and West (1975) detected a decline in nitrogen concentration with increasing distance from the shrubs. The mechanism of interaction between fourwing saltbush and crested wheatgrass is not well understood and may be unique to this combination since other workers (Rittenhouse and Sneva 1976) have reported a negative correlation between Wyoming big sagebrush (Artemisia tridentata Nutt. var. wyomingensis) crown cover and yield of crested wheatgrass.

Chenopod response to grazing and clipping has not been widely investigated, although there are indications that some chenopods are very tolerant to grazing even in mixes and grasses. Rumbaugh and others (1982) reported that regrowth following grazing on fourwing saltbush and crested wheatgrass was greater when grown in a mix than when grown alone. Prostrate kochia grown at the Nephi Dryland Field Station increased in both production and vigor when plants were grown with crested wheatgrass.

NUTRITIONAL VALUES

Protein

Protein is one of the most important nutrients in livestock diet. Serious problems may result when animals fail to obtain sufficient protein to maintain body weight. Ruminant animals require about 7 percent protein in their diets for the rumen micro-organisms to effectively digest and metabolize carbohydrates and fats (Fonnesbeck and others 1975). At protein levels below this amount, rumen function becomes severely impaired (Dietz 1972).

Shrubs contain higher levels of crude protein than grasses and forbs during fall and winter periods, but lesser amounts during spring and summer. Shrubs maintain a consistently higher protein content farther into the dormant season than do grasses. Cook and Harris (1968) reported a 75 percent loss of protein in grasses from early growth to seed formation while shrub species declined only 40 percent during the same period. Chatterton and others (1971) reported crude protein levels in Atriplex polycarpa ranging from 10 to 13 percent, although these amounts varied according to season. Among 43 accessions of Atriplex canescens, crude protein ranged from 5.3 to 17.1 percent during the winter period according to Welch and Monsen (1981), who attributed these differences to genetic variability.

Sheep will include significant amounts of chenopod shrubs in their diet when they are readily available during fall and winter periods. In a grazing study at the Nephi Field Station, Otsyina (1983) found that the protein content of shrub/grass forage selected by sheep was higher than grass forage. Protein content ranged from 5.12 to 8.9 percent in diets selected from a crested wheatgrass pasture, and 5.8 to 10.1 percent in a mixed shrub/grass pasture containing fourwing saltbush, winterfat, prostrate kochia, big sagebrush, rabbitbrush and bitterbrush.

Digestibility

Digestibility is important in determining the nutritive value of forages. The amount and composition of nutrients made available to grazing animals depends largely on the degree of digestibility of the particular forage. Digestibility depends greatly on the animal species, phenological stage of the plants, leaf/stem ratios, plant species, and to some extent, on secondary compounds in the plants that may inhibit microbial activity in the rumen (Cook and Harris 1968; Burzlaff 1971).

During the fall when both grasses and shrubs are mature, lignin content may reduce digestibility. Short and others (1973) reported a change from 68.2 to 50.2 percent in grass digestibility from May to November. Browse (twig) digestibility decreased from 86 to 36 percent from April to August while lignin content increased 60 percent.

At present, only limited information exists on seasonal browse digestibility by livestock. In October/November, in vitro dry matter digestibility levels observed in clippings were 52.2 percent for winterfat, 51.7 percent for prostrate kochia, and 47.8 percent for fourwing saltbush. At the same time, mature crested wheatgrass and fall regrowth of crested wheatgrass were 53.2 and 77.8 percent digestible, respectively (Otsyina 1983).

Diets selected by sheep on mixed shrub/grass pastures were more digestible than those selected from pure grass pastures in the fall (Otsyina 1983). In vitro dry matter digestibility of diets from pure grass pastures average 44.6 percent while digestibilities of diet materials from fourwing and mixed shrub pastures were 55.5 and 54.6 percent, respectively. The higher digestibilities of materials from the shrub pastures were attributed to increased protein content provided by the shrub component.

CONCLUSION AND RECOMMENDATIONS

Considering the existing data on chenopod shrubs, it is apparent that they have not been effectively utilized. Chenopods such as Atriplex, Ceratoides, and Kochia have great potential for improving the nutritive value of forage during the fall-winter grazing season in cold desert rangeland. Because of their favorable nutritive contribution, chenopod shrub species could be seeded in mixes with grasses as natural protein supplements to improve the nutritional value of forage for fall and early winter grazing.

Research on shrub biology and ecology should be intensified. Additional research on the nutritional value of shrubs and their management for sustained forage production under various grazing management systems is also recommended.

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DISTRIBUTION AND IMPORTANCE OF THE ATRIPLEX CASE-BEARING MOTH, COLEOPHORA ATRIPLICIVORA COCKEREL, ON SOME CHENOPOD SHRUBS, ESPECIALLY ATRIPLEX CANESCENS (PURSH) NUTT.

T. Blaine Moore and Richard Stevens

ABSTRACT: The Atriplex case-bearing moth (Coleophora atriplicivora Cockerel) appears to be a major cause of reduced seed production and foliage destruction of fourwing saltbush (Atriplex canescens [Pursh] Nutt.) on open ranges and in seed orchards. Livestock and big game grazing and predation seem to control the moth in natural populations of fourwing saltbush. In seed orchards, good control can be achieved by proper use of the insecticide malathion. Life cycle of the case-bearing moth is described.

INTRODUCTION

After several observations of insect damage to foliage leaves and seed production of fourwing saltbush (Atriplex canescens [Pursh] Nutt.) at Snow Field Station, Ephraim, Utah, steps were taken to determine the causative organism. The primary damage appeared to be done by a case-bearing moth identified as Coleophora atriplicivora Cockerell[1] (Coleophora Coleophoridae) (fig. 1).

Figure 1.--Adult Atriplex case-bearing moth.

Moths were first observed and collected by the authors from fourwing saltbush at the Snow Field Station in 1978. Plants showed extensive leaf damage, with some being completely defoliated. The larvae of the insects in question worked either side of the leaf, making an entrance hold and feeding on the leaf parenchyma and epidermal layers (fig. 2).

Figure 2.--Damage done to leaves of fourwing saltbush by Atriplex case-bearing moth larvae.

Although the damaged leaves were easy to identify, the insect was difficult to detect. The larvae doing the damage were eventually found to be in cigar-shaped cases 11.0 to 15.0 mm long and 2.5 to 4.0 mm wide (fig. 3).

More than 100 species of case-bearing moths (family Coleophoridae) occur in North America. During the first larval instar the moths are leaf miners, after which they move to the outside of the leaf, constructing a portable case in which they live throughout their larval and pupal stage. The cases are closed at the distal end and eventually become a cocoon for the pupae. Larvae inside the cases eat into the leaf, making circular mines, reaching in as far as they can to feed without leaving the case.

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[1] Heppner, J. Smithsonian Institution, Washington, D.C. Specimens identified for authors in August 1979, and are in Snow College collection.

Cases are constructed from parts of the plant upon which the larvae feed, and are lined with silk. The insects winter as partly grown larvae in cases which are fastened securely to a twig or branch with silk (Baker 1972).

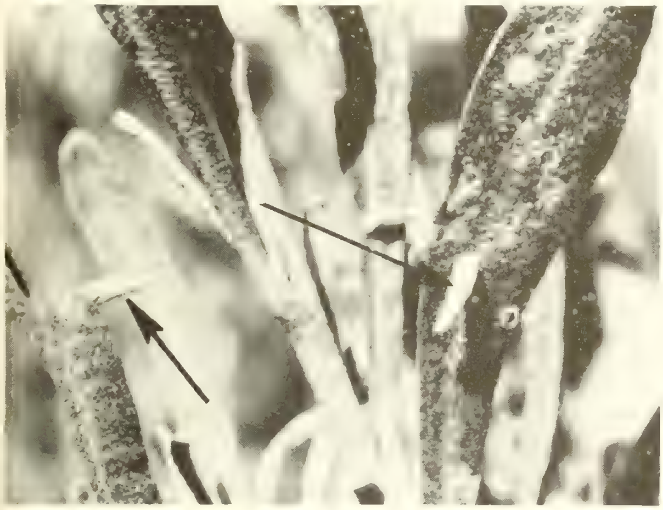

Figure 3.--Cigar-shape (arrow) of the Atriplex case-bearing moth (2d instar) attached to a leaf of fourwing saltbush.

Most species of the family Coleophoridae belong to the genus Coleophora, of which 10 species infest numerous eastern deciduous trees (Baker 1972). Only one species, C. laricella (Hubner), is of importance in western forests, infesting western larch (Larix occidentalis Nutt.) (Furniss and Carolin 1977).

California case-bearers (C. sacramenta [Heinrich]), have been found to infect willow (Salix sp. L.), almond (Prunus amygdalus Batsch.), and apricot (Prunus armeniaca L.). Infestations on apple, cherry, peach, plum, and pear have also been reported (Essig 1948). The need for control is obvious when complete defoliation is caused by these insects.

The only reference to C. atriplicivora known by the authors and Davis[2] is by T. D. A. Cockerell (1898). His reference describes the adult only, with brief mention of his inability, except in rare instances, to raise adults from larvae.

Description (Adapted from Cockerell 1898)

The adult Atriplex case-bearer (fig. 1) is from 10 to 20 mm long. The head, thorax, and primaries (forewings) are white with a delicate ochreous tint. Secondaries (hindwings), abdomen, legs, and underparts of the body are silvery-white; hind tibiae are pale ochreous, clothed with long white hair. Fringes are pale, faintly greyish, tinged with ochreous. The longest fringe on primaries is longer than the greatest diameter of the wing. Primaries are superficially without streaks, but close examination shows that the courses of the veins are broadly ochreous-tinged, while the intervals are narrowly white, producing an obscure longitudinal streaking. This is somehow intensified with the intervals being peppered with minute dark grey specks. Palpi are quite long (1.5 mm), the penultimate segment with a well-marked terminal brush of scales. Antennae are delicately annulated with white and pale grey, the basal two-fifths heavily clothed so as to appear considerably thickened. Abdominal segments 2 to 6 (all specimens examined by the authors had 6), each with a pair of longitudinally narrow brown (i.e. scaleless) marks, one on each side of the median line.

METHODS

Extensive observations were made in 1980 and 1981 at Snow Field Station and in native populations of fourwing saltbush throughout Utah, northern Arizona, and southern Nevada for the presence of the Atriplex case-bearing moth. Fourwing saltbush populations were regularly examined during the months of June and July at Bald Mountain, Chester, and Palisade State Park, all in Sanpete County, and Marysvale (Piute County). Collections and observations were made at St. George (Washington County), at the mouth of Spanish Fork Canyon (Utah County), near Grantsville (Tooele County), near Pipe Springs Arizona, and near Bunkerville, Nevada. Observations were also made to determine if the moth occurred on other chenopods.

Five years (1978 through 1982) of field observations and laboratory rearings made it possible to determine and confirm the life cycle of the Atriplex case-bearing moth.

A quantitative study was begun in 1981 to determine number of moths and exact damage to seed production on fourwing saltbush at the Snow Field Station. Twelve female plants each from two populations of related fourwing saltbush were selected. Eight branches 6 to 8 inches (15 to 20 cm) long were marked two on each of the south, east, north, and west sides of each plant. Branches were located 18 to 24 inches (45 to 60 cm) above the ground. One population was sprayed with the insecticide malathion in early June and mid-June to kill larvae that have overwintered and were moving onto foliage and again in mid-August to kill larvae of the new generation. Malathion was applied at the rate of 5 pounds of active ingredients per acre (5.6 kg/ha). Application was made with a ground rig. Fourwing saltbush plants were sprayed until the spray was dripping from the leaves. The total number of larvae present on each of the marked branches was counted on June 4 (4th instar), June 16 (5th instar), July 10 (pupae), July 28 (2d instar larvae of 2d generation).

Ten plants each from the sprayed and nonsprayed populations were selected at random. Seeds from each plant were collected, cleaned, and weighed. Seed productions were compared by a "t" test (Woolfe 1969).

[2] Davis, D. S. Smithsonian Institution, Washington, D.C. Personal communications; 1982.

RESULTS

Distribution

The Atriplex case-bearer was found on several species of the plant family Chenopodiaceae. By far the largest number were found in cultivated stands of fourwing saltbush. Specimens were observed in widely scattered native stands from Washington County in southwestern Utah to Tooele County in northwestern Utah.

Cases were also observed on A. lentiformis (Torr.) Wats., A. tridentata Kuntze, A. confertifolia (Torr & Frem.) S. Wats., Sarcobatus vermiculatus (Hook.) Torr., and Halogeton glomeratus (C.A.) Mey. in Ledeb. Of these, A. tridentata had the greatest infestation. A. confertifolia in most areas had only a few, and only two cases each were observed on H. glomeratus and S. vermiculatus. Those on A. tridentata and A. confertifolia were hatched out in the laboratory and proven to be the same species as occurs on A. canescens.

A similar case-bearer was found on rubber rabbitbrush (Chrysothamnus nauseosus [Pall.] Britt. var. graveolens [Nutt.] Piper). The cases were more than 15.0 mm long, were somewhat more slender than those of the Atriplex case-bearer (2 to 2.5 mm wide), and were devoid of any debris characteristically found on C. atriplicivora. Species identification was not made for the rabbitbrush case-bearer.

Life Cycle

The adult Atriplex case-bearers begin pairing up in late June and remain in the mating position (genitalia connected and heads pointed in opposite directions) for 2 or 3 days (fig. 4-1). Eggs, about 0.17 mm in diameter, sculptured and light amber in color, are deposited, one per leaf, on the smooth surface of the leaf Atriplex, or in some other feature which would give protection (fig. 4-2). Within one week the eggs hatch, and the first instar larvae (fig. 4-3) burrow from their shells directly into the leaf, becoming mining insects. They remain as leaf-mining larvae throughout this first instar. These insects then change their eating habits as they become too large to remain leaf miners. The larvae emerge from the leaf through emergence holes and begin to spin cigar-shaped cases. There is only one larva in each case. The larvae will feed for a time on the leaf (fig. 4-4), then move to a place on the larger branches of the fourwing saltbush (fig. 4-5). Here they go into diapause sometime before cold weather (September or early October). Diapause is probably triggered by photoperiod, although other factors might also be involved, such as lower nighttime temperatures, slowing up of plant growth, and possibly the production of insect-inhibiting chemicals (Maugh 1982).

As soon as new leaves begin to appear on fourwing saltbush, the second instar larvae of the case-bearer release their hold on the stem and move up from the large basal branches of the plant and begin to feed. They seem to feed on the young opening leaves and flower buds, then later move to the larger leaves of the plants. They eat into a leaf from either surface and, while remaining in the case, begin to feed on the parenchyma and epidermal tissues of the leaf. By reaching into the entrance hole of the leaf, they extend themselves as far as they can go without leaving their cases. They make circular excavations in the leaf, with entrance

Figure 4.--Coleophora atriplicivora life cycle: (1) male (right) and female (left) moths mating (late June), (2) egg on lower surface of leaf of Atriplex canescens, (3) 1st instar larva (mid-July), (4) 2d instar larva feeding on leaf (late July), (5) 2d instar larva in diapause (September-May), (6) 4th instar larva in case (middle of June), (7) pupa removed from cases (late June), (8) adult moth (early July).

Figure 5.--Leaves of fourwing saltbush completely destroyed by the activities of Atriplex case-bearing moth larvae.

Figure 6.--Case (arrow) of an Atriplex case-bearing moth disguised with floral parts among the male flowers of fourwing saltbush.

holes roughly in their centers. When they cannot reach any additional food, they move to a new location, make a new entrance hole and excavate. This process is repeated many times until the leaf is destroyed (fig. 5).

By using the silk they produce, along with the plant debris, these larvae build new cases, at each of the earlier moults, to compensate for their increase in size, with possible exceptions of the moults between the fourth and fifth instar. Positive evidence of cases at this stage was not obtained (fig. 4-6 shows 4th instar larva in case).

The larval case spun by the larva is silk. Movement of larvae on the plant causes considerable material to adhere to the outside of the case. This plant material frequently consists of flower parts which break up the smooth outline of the case. This is a good example of protective adaptation for the insect (fig. 6), and is especially apparent on male plants.

The cases on female plants, which pick up some materials, are more readily seen on the green leaf or in the inflorescence. Because cases on female plants are easily detected, they may fall prey to predators, hence are fewer in number.

The larvae upon completing their last instar, move to places on the stems where several small branches arise from a node (fig. 7). It is here that pupation occurs; the larval case now becomes the pupal case (fig. 4-7, pupae removed from cases).

Figure 7.--Pupal case (arrow) of an Atriplex case-bearing moth after having migrated to the axil of branches of fourwing saltbush.

This case is 12 to 15 mm long and 2.5 to 4.0 mm wide at its greatest width. The adult moths appear from 1 week to 10 days after the beginning of pupation (fig. 4-8).

Moth Abundance and Its Effect On Seed Production

There was a change in the number of individuals at three points in the life cycle of the Atriplex case-bearing moth (table 1). The number of insects varied greatly between individual shrubs and between generations. However, insect numbers did not vary among the four sides (south, east, north, and west) of an individual shrub.

Table 1.--Number of insects on eight branches 6 to 8 inches (15 to 20 cm) long on each of 12 fourwing saltbush plants on June 4, June 16, July 10, and July 28.

Plant No.	June 4 4th instar	June 16 5th instar	July 10 pupae	July 28 2d instar generation
1	42	38	33	17
2	52	52	35	55
3	24	23	23	31
4	56	52	52	68
5	54	49	34	69
6	75	69	51	107
7	45	43	46	100
8	65	59	43	113
9	56	46	48	63
10	181	171	96	122
11	123	119	98	79
12	83	83	93	63
Avg. per plant	71	67	52	74

Seed production was highly significantly affected by the presence of the moth. Mean seed weight per sprayed plant (no moths) was 290 grams, compared to a mean seed production of only 2.5 grams for nonsprayed plants (table 2). In three native stands of fourwing saltbush, where infestation of the moth was found, seed production was near zero.

Grazing seemed to have an effect on moth density and seed production. Atriplex tridentata is found in the Sanpete Valley along roadways and in other nongrazed areas. In one such area there was a 5-acre field of trident saltbush next to the roadway. Along the roadway and fencelines the case-bearing moth was abundant and no seed production occurred. In the field where sheep pastured in the spring and autumn no cases could be found, and there was good seed production.

A number of native fourwing saltbush stands were studied. In those stands where grazing occurred (sheep, cattle, deer) few moths were found and seeds were produced. Evidently, many cases containing larvae are eaten by animals, especially during spring and summer grazing when the larvae are predominantly on the foliage.

Table 2.--Dewinged fourwing saltbush seed production (grams) on 10 sprayed (Malathion) and 10 nonsprayed plants.

Plant No.	Sprayed	Nonsprayed
1	368	5
2	260	0
3	100	6
4	164	0
5	300	0
6	336	10
7	244	0
8	632	4
9	204	0
10	300	0
Total	2,899	25
Avg. per plant	290	2.5

General Observations

Van Epps[3] found and reported to the authors that all the male plants of *A. canescens* on the Utah State University's Snow Field Station study area were severely damaged by *C. atriplicivora*. Fourwing saltbush plants on this study area were inspected. The female plants did not appear to be damaged to any great extent, however, no seed was produced. On close examination it was easier to find cases on female plants than on male plants. This was due to better camouflage for the cases in the male inflorescence (fig. 6). Additional observations were made at three range locations. In all instances more cases were observed on female plants than on male plants. One really had to look to find cases on the male plants. The cases on male plants that were found were among the inflorescences.

After looking for the cases, each bush was swept with a beating net. More larvae were found on the male plants than on the female. Because cases on female plants were more conspicuous, they could be more susceptible to predation. Birds could be major predators, though birds themselves were not observed actually taking the larvae. However, they were quite active in fourwing saltbush stands during early morning hours. The rock wren (*Salphinctes obsoletus* [Say]) and some sparrows (species unidentified) were frequent visitors to the plants. A clerid beetle (*Hydnocera* spp. Newn) was observed while moving along a branch of *A. canescens* with a case in its mandibles. Insects, however, are generally less important as predators than as parasites.

[3] Van Epps, G. A. Utah State Agricultural Experiment Station, Ephraim, Utah. Personal communication; 1982.

Of the more than 200 adult moths which were raised from larvae in the laboratory, none were found to have been parasitized. This is not to suggest that parasitism does not exist in this group, but simply on these occasions they were free of parasites. Adults were raised from the last instar larvae and from pupae gathered in the field, giving potential parasites ample opportunity to lay their eggs on them. Adults were raised in the laboratory during three successive summers with all hatching and no evidence of parasites.

CONCLUSION

The Atriplex case-bearing moth, C. atriplicivora was found to be abundant in cultivated monoculture seed orchards of fourwing saltbush, where it caused a great amount of foliage and seed damage. In natural populations of A. canescens, however, moth populations were not observed to be as great as in seed orchards. The moth was found on a number of other chenopods.

Feeding by browsing animals such as deer, cattle, and sheep seemed to play an important role in moth control. These animals feed on the plants during early spring and summer when the overwintering larvae are becoming active and are going through various stages of their life cycle on the leaves. In the fall these insects migrate to the stems to go into diapause. Very little natural predation was observed during the study. Some birds may take the larvae, and a clerid beetle was observed with a case in its mandibles.

No parasites were found associated with the more than 200 moths raised from larvae in the laboratory.

CONTROL OF ATRIPLEX CASE-BEARING MOTH

In central Utah seed orchards the Atriplex case-bearing moth can be successfully controlled by spraying the insecticide Malathion (5 pounds of active ingredients per acre [5.6 kg/ha]) in early June with followup spraying in mid-June moving up onto the foliage. An additional spraying should be done by mid-August to kill the new generation larvae. Plants sprayed with Malathion produced 100 times more seed than did plants not sprayed.

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STATUS OF INFORMATION CONCERNING INSECTS ASSOCIATED WITH SELECTED SPECIES OF ATRIPLEX

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ABSTRACT: The value, uses, needs, and limitations of a Utah State University collection of approximately 140 insect species associated with *Atriplex* spp. are discussed. Examples of families and species of insects collected, their guilds and general impacts on vegetation and reproduction of *Atriplex* species are presented. Needs are outlined for interdisciplinary research to: (a) assist seed analysts, (b) develop acceptable cultural, biological, or chemical management strategies to control insects, and (c) benefit those responsible for range improvements, management, and native plant enterprises.

INTRODUCTION

Entomologists at Utah State University (USU), Logan, Utah, have collected rangeland insects, including those from *Atriplex*, for approximately 60 years according to Knowlton (1932).

Until recently insects associated with *Atriplexes* had not been a priority for USU researchers because their major efforts have been collecting and identifying rangeland insects in general, but observers of rangelands report they have seen devastating impacts of mealybugs and root borers on large acreages of *Atriplex* for many years (Sharp 1983, personal communication.)[1]

Demands for native plant seeds, for containerized plants, and bareroot stock for land rehabilitation have given new importance and emphasis to studies of insects associated with forbs and shrubs.

Investigations of selected shrub and forb insects of major importance, their ecotypes, and the beneficial and injurious insects associated with them were expanded in 1979 when a five-year Ecosystems Reconstruction Project was formalized with USU and the National Science Foundation. In-depth studies of bitterbrush, *Purshia tridentata* (Pursh) DC., were initiated by USU in 1981.

Taxonomic studies and general observations of insect injury to *Atriplex* species and their seed have been included in research to date at USU. The announcement of this *Atriplex* symposium has created an awareness that the *Atriplexes* merit a high research priority for entomologists and has resulted in a closer examination of *Atriplex* data now on hand.

Some data presented here come from the unique orchards established by Gordon Van Epps at Ephraim and Nephi, Utah. The orchards had been infested with insects and offered an opportunity for researchers at Snow College and USU to cooperate in studies of insects of *Atriplex* and several other rangeland plants grown as monocultures.

Dr. G. E. Bohart, an experienced insect taxonomist, has participated as an entomological consultant for a number of rangeland studies that included insects. His valuable collections have been incorporated in the USU range insect collection. Dr. Bohart has helped prepare data to show the present status of information concerning insects associated with several species of *Atriplex*.

The objective of this paper is to summarize some of the information available about the species of insects collected from *Atriplexes*, their relative abundance, known or suspected impacts on plants and seed, management principles, problems, and needs associated with producing, processing, and evaluating *Atriplex* seed.

The first essential step in diagnosing and solving problems with insects associated with *Atriplex* is correct identification of the insects. The list of insects collected from *Atriplexes* now includes 142 species and the list is increasing, but much remains to be done on the identification of these insects.

Little research has been done on biologies of most of the insects associated with *Atriplex* species, but inasmuch as the general behaviors and impacts of insect groups that have been studied on other host plants often are similar, helpful information can be extracted from the taxonomic data and field observations now on hand about *Atriplex* insects.

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[1] Dr. Lee A. Sharp, Professor of Range Resources University of Idaho, Moscow, Idaho.

ATRIPLEX INSECT LITERATURE

Much information exists about many aspects of Atriplex bionomics: its wide distribution, ecotypes, physiology, adaptability, nutritional value, reproduction, and animal associations (Cristi 1971; McArthur and others 1978; Monsen 1975; Plummer and others 1966; Stevens and others 1981).

Knowlton (1932) lists the the following Atriplex species as plant hosts of the beet leafhopper Eutetix tenellus (Baker), a destructive pest of sugar beets and tomatoes: powelli S. Wats., canescens (Pursh) Nutt., argentes Nutt., confertifolia (T. and F.) S. Wats. patula hastata (L.), nuttalli falcata (Jones), nuttalli S. Wats., rosea L., and truncata (Torr.) A. Gray.

Some mimeographed reports found at USU are those such as that by Knowlton (1966), which lists insects he or others found injuring Atriplex and other rangeland plants.

US/IBP Desert Biome studies summarized by Sferra[2] (1974, 1975, unpublished data) lists insects found on Atriplex, and other range plants, but few reports of specific research or published papers concerning the detailed biologies or economic impacts of injurious or beneficial insects on Atriplexes have yet been located.

In 1983 a cooperative project between USU and the U.S. Department of Agriculture, Forest Service Intermountain Forest and Range Experimentation Shrub Laboratory at Provo, Utah, was initiated to collect a list of known insects associated with rangeland shrubs, including Atriplexes, and to review and cross-index all related literature that can be found.

There is a scarcity of information in the literature about insects associated with the Atriplexes. Furniss (1972) listed a number of insects collected from browse plants, but none is indicated for Atriplex. In a publication concerning important shrub insects, Furniss and Barr (1975) listed only one species from A. canescens. A range insect publication commissioned by the Society for Range Management (Hewett and others 1974) does not list any insects associated with A. canescens.

Watts and others (1982) pointed out that there is an absence of detailed biological and control technology literature on insects of browse plants and that emergency control of Orthezia scales on Atriplex spp. might be justified if methods were available.

Moore[3] (1983, unpublished data) reports studies of a case-bearing moth of A. canescens. A snout moth (Pyralidae) was reported to have killed A. confertifolia plants (Stoddard and others 1975). Vallentine (1971) indicated grasshoppers injured a higher proportion of fourwing saltbush seedlings than did rabbits.

Palmer (1952) recorded Xerophilaphis tetrapteralis (Cockerell), an aphid found on "Atriplex Saltbush."

A USU publication presents an introduction to rangeland insects (Haws and others 1982a).

INSECTS AND ATRIPLEX SPECIES

Present evidence from native and domestic Atriplex communities suggests that the kinds and densities of insects associated with different plant ecotypes vary considerably (Meadows 1983, unpublished data).[4]

Table 1 lists 107 insect species collected by sweeping Atriplex canescens (Pursh) Nutt. in orchards at Ephraim and Nephi, Utah, and shows the families categorized into guilds (insects that utilize the same resource the same way, e.g. feed on roots, gather pollen). Many records of genera and species are combined in this listing of insect families. Use of family identifications is of limited value in diagnosing and solving insect problems because so many different kinds of insects may be found within a family. Table 1 shows that some of the injurious or beneficial impacts of the immature forms and their adults may be different.

Having to distinguish the immature insects from their adults greatly increases taxonomic tasks and complicates the determination of insect impacts because their feeding patterns may be vastly different. (See table 1)

Table 2 demonstrates the kind of information concerning insect genera and species that is combined by families in table 1. Table 2 also shows why it is necessary to have insect collections from specific geographical regions. Note there is only one overlapping species collected in these two areas, the ant, Formica lasioides. It is necessary to collect insects regularly during the year, and perhaps for several years, using various collecting methods, to get accurate, complete samples of the insects present in an area.

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[2]Sferra, P. R. Classification and quantification of invertebrate activity and the role of invertebrates in nitrogen processing in plants, litter and soil in Curlew Valley. US/IBP Desert Biome Res. Memo 74-28; Ecology Center, Utah State University, Logan, Utah; 1974. 8 pp. Same 1975. 6 pp. (unpublished)

[3]Moore, T. Blaine. Distribution and economic importance of the case-bearing moth, Coleophora atriplicivora, on some Chenopod shrubs, especially Atriplex canescens. Proceedings, this symposium.

[4]Meadows, Roy W. Graduate student, Department of Biology, Utah State University, Logan. Unpublished data.

Table 1.--Insects collected from *Atriplex canescens* in 200 sweeps near Ephraim and Nephi, Utah, on August 1, 1981, and September 7, 1981. Shown are order and family, number of insect species collected, and feeding habits (guilds) of adults and immatures for each family.

Order/Family	Number	Feeding habits of adults/immatures
Coleoptera	12	Variable feeding habit/same as adults
Coccinellidae	2	Aphid, mite predators/same as adults
Chrysomelidae	5	Leaf skeletonizers/same as adults
Melyridae	1	Aphid, mite, small larva predators/ predators of soft-bodied insects near plant crown
Meloidae	1	Chew leaf and flower tissue/some predators of bees, some in grasshopper egg masses
Mordellidae	1	Chew leaf tissue/same as adults
Staphylinidae	1	General predators/same as adults
Lathridiidae	1	Feed on fungi/same as adults
Hemiptera	13	Sap or blood feeders/same as adults
Pentatomidae	2	Most pierce leaves, reproductive parts, a few predators/same as adults
Lygaeidae	3	Pierce fruits, seeds, soft tissue, a few are predators/same as adults
Nabidae	1	Predators of aphids, immature mirids/same as adults
Reduviidae	1	Predators of other insects/same as adults
Miridae	3	Pierce leaf, bud, young tissue/same as adults
Anthocoridae	1	Predators of thrips, mites; sometimes pierce flower parts/same as adults
Tingidae	1	Pierce leaf epidermis/same as adults
Neididae	1	Pierce leaves and stems of herbaceous plants/same as adults
Homoptera	17	Sap feeders, many oviposit in plant tissue
Cicadellidae	14	Pierce leaf tissues/same as adults
Membracidae	1	Pierce leaf and stem tissues/same as adults
Delphacidae	1	Pierce leaf and stem tissues/same as adults
Psyllidae	1	Pierce leaf tissues/same as adults
Hymenoptera	44	Most feed on pollen and/or nectar, some omnivorous
Halictidae	4	Visit flowers, store pollen and nectar/eat pollen and nectar stored by adults
Sphecidae	5	Take nectar from flowers, store specific insects in nest/feed on insects stored by the adults
Eumenidae	1	Take floral nectar, store lepidopterous larvae/eat larvae stored by adults
Formicidae	3	Omnivorous--eat seeds, nectar, honeydew insects, etc./eat food supplied by the adults
Bethylidae	2	Take nectar, oviposit in beetle larvae "in situ"/consume beetle larvae from within
Dryinidae	1	Oviposit in leafhoppers/consume leafhoppers from within
Pteromalidae	5	Eat nectar and pollen, oviposit in host insects/consume host insects from within
Eulophidae	9	Eat nectar and pollen, oviposit in host insects/consume host insects from within
Encyrtidae	4	Eat nectar and pollen, oviposit in host insects/consume host insects from within
Eurytomidae	2	Some oviposit in host insects, some in seeds or stems/consume the oviposition medium
Chalcididae	2	Eat pollen and nectar, oviposit in host insects/consume host insects from within
Scelionidae	1	Oviposit in eggs or insects/consume the egg or host from within
Mymaridae	1	Oviposit in insect eggs/consume the host egg from within
Braconidae	4	Eat nectar and pollen, oviposit in insects or spiders/consume host from within

Table 1.--Continued.

Order/Family	Number	Feeding habits of adults/immatures
Diptera	16	Most species feed on nectar and/or pollen, animal excrement etc./various but usually feed inside food material
Tachinidae	2	Feed on nectar or pollen, oviposit in insects/consume host insects from within
Calliphoridae	1	Feed on floral products, exudates of decay/scavengers of decaying substances
Anthomyiidae	1	Most feed on nectar, other plant exudates/some are scavengers, some feed on bulbs, roots, some on old carrion
Tephritidae	1	Drink nectar, other plant exudates/some eat fruit, some induce plant galls, especially in heads of Compositae
Otitidae	2	Drink nectar, other plant exudates/mostly eat decaying plant materials
Milichiidae	1	Drink nectar, other plant exudates/saprophagous or copraphagous
Sepsidae	1	Drink nectar, other plant exudates/feed in excrement or decaying plant material
Chloropidae	3	Feed on plant or animal exudates/feed on roots or stems, some scavengers in plant material
Chamaemyiidae	1	Feed on plant exudates/some parasitic in scale insects
Bombyliidae	1	Feed on nectar, oviposit near or on host insects/most external parasites of bee or wasp larvae, grasshopper eggs
Stratiomyidae	1	Some feed on nectar, pollen/predaceous or scavengers under bark, in excrement, or other organic matter
Pipunculidae	1	Drink plant exudates, oviposit in leafhoppers/ consume host insects from within
Lepidoptera	1	Drink nectar/consume plant tissue
Hesperiidae	1	Drink floral nectar/chew leaf material
Orthoptera	1	Chew leaves and stems of various plants
Acridiae	1	Chew leaves and stems/same as adults
Odonata	1	Predaceous or don't feed as adults/predaceous and aquatic as immatures
Coenagrionidae	1	Don't feed/predaceous in ponds, streams
Thysanoptera	2	Some rasp plant epidermis, some predators on other thrips/same as adults
Total species	107	

Table 2.--Data showing differences in the species and relative abundance of insects collected from Atriplex canescens (Pursh) Nutt. at two different dates and locations.

Bonanza, Utah, June 7, 1976, insects collected in 50 sweeps 12-inch net			Twin Falls, Idaho, Aug. 16, 1983, insects collected in 80 sweeps 12-inch net		
Order/Family	Genus & species	Number of individuals	Order/Family	Genus & species	Number of individuals
Hymenoptera (wasps, ants, etc.)			Hymenoptera		
Scelionidae	*Trissulens utahensis* Ashm.	2	Brachonidae	*Agathis gibbosa* (Say)	2
Eulophidae	eulopid #1[1]	4			
Formicidae	*Dorymyrmex pyramiscus* (Roger)	2	Formicidae		
	Formica lasioides Emery	3		*Formica lasioides* Emery	8
Diptera (flies, gnats, etc.)			Diptera		0
Chamaemyiidae	*Leucopis* #1	2			
Chloropidae	*Siphonella* #1	2			
	Philygria debilis Loew	2			
Coleoptera (beetles)			Coleoptera		
Bruchidae	bruchid #4	2	Chrysomelidae	*Monoxia elegans* Blake	232
		0	Melyridae	*Collops bipunctatus* Say	2
Lepidoptera (butterflies and moths)			Lepidoptera		
			Psychidae	psychid #1	3
Hemiptera (true bugs)			Hemiptera		
Pentatomidae	*Thyanta punctiventris* V.D.	7	Pentatomidae	*Chlorochroa sayi* Stal	2
Total		[2]13			249

[1]Numbers or letters identify unknown species that have been or will be sent to specialists for identification.

[2]Of 34 species only those 13 with more than one individual collected are shown.

Seven of the insects in table 2 are not identified to species. The unidentified specimens will have to be sent to taxonomic specialists for further identification.

Of 34 species collected at Bonanza, 13 (38 percent) are parasites or predators of other insects, and might be considered beneficial from the human viewpoint. Two species are considered "visitors" (not feeding or having any direct impacts or associations with fourwing saltbush). The remaining 19 species (59 percent) contained both chewing/rasping insects and sucking insects, generally considered to be injurious.

The size of the insects varied from about .32 inch (.75 mm) to more than 2 inches (50 mm) in length. Size or numbers of individuals are not always reliable criteria of the importance of an insect. For example, a population of minute egg parasites might almost completely destroy a generation of larger insects. A few small leafhoppers carrying viruses may infect an entire group of plants. Small seed chalcids may drastically reduce a plant's seed crop, but some migrating grasshoppers can destroy nearly all vegetation in their path.

The conclusions from this small collection cannot be extrapolated through a whole season or to other locations. The kinds and numbers of insects that can be collected vary considerably at different times of the day, under different conditions of temperature, sunlight or cloudiness, place to place, week to week, month to month and year to year.

Some insects hatch from eggs in the spring, develop in a few weeks, mature, and lay eggs that remain as eggs for more than nine months. Others overwinter as adults, pupae, or larvae, and some insects produce a new generation several times during a season. There are many combinations of these kinds of life and seasonal cycles.

Table 3 shows that in this particular sample a large portion of the insects collected are beneficial, that is, pollinators, parasites, or predators of other insects. In this sample there were a few more beneficial insects than harmful ones. Some of the insects were neutral in that they appear to neither injure nor benefit the plants. The proportion of injurious and beneficial insects shown in table 3 undoubtedly changes during the year and in different areas.

INSECTS AFFECTING ATRIPLEX SEED

Much of the commercial Atriplex seed that has been examined at USU was infested with or damaged by chewing or plant-sucking insects. Damage occurred as the seed developed or when it was in storage. Among approximately 300 samples of commercial seed examined, many samples contained living dermestid larvae that were eating the seed.

Seed chalcids are tiny wasp-like insects that inject eggs into the developing seed. The larvae that hatch from the eggs grow as the seed develops. The adults may be distributed when the seed is planted. Inasmuch as a seed containing an insect weighs almost the same as a noninfested seed, infested seeds are not always removed in the gravity cleaning process. Seeds containing chalcids may be planted with good seed. (See fig. 1)

Table 3.--Approximate status of 50 families[1] of adult (AD) and immature (IM) insects collected from *Atriplex canescens* (Pursh) Nutt. near Nephi and Ephraim, Utah, 1979.

I Beneficial		II Injurious		III Neutral[2]	
AD	IM	AD	IM	AD	IM
21	30	22	22	13	7

[1]Numbers do not total 50 because some insect species within the same family have different feeding and behavior patterns. There were more beneficial than injurious insects.

[2]Neutral=insects visit or rest on the plants, do not feed or lay eggs on them.

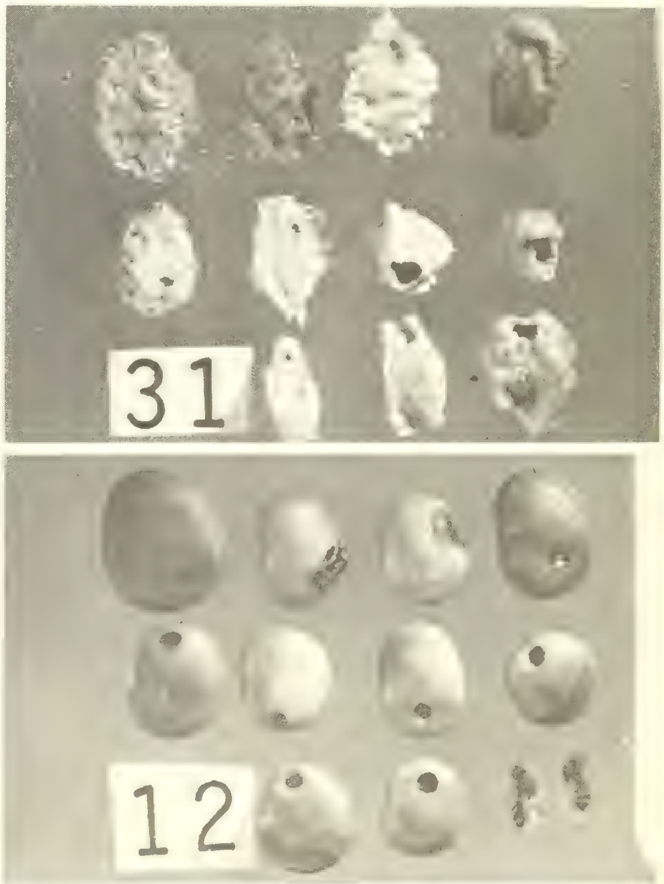

Figure 1.--Top: *Atriplex* seeds showing seed damaged by chewing insects. Partial bodies of seed chalcids were found in some seeds. Bottom: Adult chalcids and their exit holes in smooth seeds (*Rhus trilobata* Nutt.) are easier to see than those in *Atriplex* seed.

In order to get an idea of the impacts of insects on the seed of three Atriplex species, seven lots of commercial seed were obtained and analyzed.

Ten one-inch square samples of seed were selected at random from each of the seven lots by pouring the seed evenly over the bottom of a petri dish with a grid in the bottom. The seed was from six geographical locations.

Each seed was clipped into two parts and classified as: (1) good (nondamaged seed); (2) damaged by chewing insects (seed partly eaten or containing dead insects); (3) damaged presumably by sucking insects (brown and shriveled as had been observed in other kinds of seed damaged by insects caged on seed). Some seed was categorized as immature seed (green and shriveled, not discolored or eaten), but this seed was not included in the analyses. A total of 985 seeds were examined. (See tables 4 and 5)

Table 4.--Results of analyses of seven commercial lots of Atriplex seed for insect damage. Data were collected from ten randomly selected 10-inch squares from each seed lot. Species abbreviations are as follows: ATCU=Atriplex cuneata A. Nels.; ATGA=A. gardneri (Moq.) D. Dietr.; ATCA=A. canescens (Pursh) Nutt.; ATCO=A. confertifolia (T. and F.) S. Wats.[1]

Section A

Sample/species	Percentage nondamaged seed
Watson, Utah, #1, ATCU	63.5 a
Lincoln County, Wyoming, ATGA	64.1 a,b
Watson, Utah, #2, ATCU	73.5 b
Lincoln County, Nevada, ATCA	81.3 c
Carbon County, Utah, ATCA	84.2 c
Juab County, Utah, ATCO	85.7 c
Sanpete County, Utah, ATCO	100.0

Section B

Sample/species	Percentage of seeds presumably damaged by plant-sucking insects
Juab County, Utah, ATCO	0.0 a
Sanpete County, Utah, ATCO	0.0 a
Carbon County, Utah, ATCA	12.8 b
Lincoln County, Nevada, ATCA	17.1 b,c
Watson, Utah, #2, ATCU	24.1 c,d
Watson, Utah, #1, ATCU	31.0 d,e
Lincoln County, Wyoming, ATGA	34.5 e

(con)

Table 4.-- (con)

Section C

Sample/species	Percentage of seed damaged by chewing insects
Sanpete County, Utah, ATCO	0.0 a
Lincoln County, Wyoming, ATGA	1.3 a,b
Lincoln County, Nevada, ATCA	1.6 a,b
Watson, Utah, #2, ATCU	2.4 a,b,c
Carbon County, Utah, ATCA	3.0 b,c
Watson, Utah, #1, ATCU	5.4 c
Juab County, Utah, ATCO	14.2

[1]Data were converted to percentages based on total number of seeds in a sample and the data transformed using an arcsine-square root function. Analysis of variance and LSD tests @ P<.05. Treatment means with the same letters are not significantly different.

Table 5.--Summary of damage due to plant-sucking and chewing insects in each of the seven seed samples. Listing is ranked from lowest to highest overall damage.

Sample/species	Percentage damage: Presumed plant-sucking insects	Chewing insects	Total
Sanpete Co., Ut./ATCO	0.0	0.0	0.0
Juab Co., Ut./ATCO	0.0	14.2	14.2
Carbon Co., Ut./ATCA	12.8	3.0	15.8
Lincoln Co., Nev./ATCA	17.1	1.6	18.7
Watson, Ut., #2/ATCU	24.1	2.4	26.5
Lincoln Co., Wyo./ATGA	34.6	1.3	35.9
Watson, Ut., #1/ATCU	31.0	5.4	36.4

ATCU=Atriplex cuneata ATGA=A. gardneri
ATCA=A. canescens ATCO=A. confertifolia

Data obtained from evaluating the seed damage shown in tables 4 and 5 were subjected to analysis of variance examination as a completely randomized design, with each location being a treatment and each one-inch square sample being a replicate. Percentage data were transformed using an arcsine-square root function.

A significant difference between treatment means was indicated by data for the seed of all three Atriplex species. Treatment means were examined using a protected LSD test to determine which locations had significantly different percentages of nondamaged and damaged seed. The percentage of each seed type for each location and the results of the LSD tests are shown in tables 4 and 5.

Seed losses attributed to plant-sucking insects ranged from zero (in the Sanpete Co., Utah, sample) to 31 percent (Watson, Utah #1). Losses attributed to chewing insects ranged from zero (Sanpete Co., Utah, sample) to more than 14 percent (Juab Co., Utah, sample). Total losses attributed to insects ranged from zero (Sanpete Co., Utah, sample) to more than 36 percent (Watson, Utah #1).

It appears from the analyses that prospective users of Atriplex seed may expect to encounter a wide variability in seed quality from different sources. Several conclusions may be drawn from this limited, preliminary study: (1) Some customers are paying for nongerminating seed. (2) Seeding rates from some lots of seed will have to be increased to obtain desired numbers of plants. (3) It is likely that new or additional insect pests will be introduced into areas where infested seeds are planted, unless seed is treated to kill the insects. (4) It is probable that large amounts of seed are being destroyed by insects. The 36 percent loss represented by these data does not include damaged seed lost before or during seed collection, or that removed during the cleaning processes, (5) Seed analysts need criteria for determining and certifying quality of native seed, and as a guide for setting seed prices.

There is little doubt that *A. canescens* seed quality, quantity, and longevity can be increased substantially by appropriate insect control strategies. Proper selection and use of suitable control methods requires: (a) legal registration of pesticides, (b) knowledge about the life cycles and seasonal growth patterns of the plants' and insects, and (c) biological facts about other components in the plant's ecosystem.

It appears that one Atriplex seed orchard observed may have been severely infested with mites as a result of the misuse of insecticides. In agriculture it has been a common experience to have crops become infested with mites when insecticides destroyed beneficial insects. The mites have become worse pests than the original target insects (personal experience of authors).

USU ATRIPLEX INSECT COLLECTION

The USU collection of insects associated with Atriplex are primarily from the Bonanza area of Eastern Utah, Ephraim and Nephi, and Curlew Valley, Utah, Idaho Falls, and Kemmerer, Wyoming. The task of obtaining a more complete collection from native and introduced Atriplex species by using various collecting methods to obtain insects from other geographical ecosystems is yet to be completed.

Most of the insects now in the USU rangeland insect reference museum have been collected with insect sweep nets. This means that some insect species present in rangelands may not be represented. Fast-flying insects, those that escape easily (such as grasshoppers), and insects that are nocturnal or that live under the soil surface, may not be collected by sweeping, although the adults of some are. Many insects that were collected in pit-fall traps have not yet been incorporated into the collection. Some other methods of collection have been employed, such as soil samplers, malaise traps, and light traps. Undoubtedly these methods will be utilized more extensively in the future.

Having a representative collection of identified range insects from the western states is an important contribution to the development of new principles of range improvement and management. The USU collection is available to help rangeland managers and others in: (a) setting up collections for specific areas; (b) diagnosing problems; (c) helping select proper combinations of plants for revegetation; (d) selecting insect-resistant varieties; (e) developing improved services from seed laboratories; (f) producing improved quantities and qualities of seeds; (g) calculating economic losses; (h) determining need for pollination; and (i) developing models and management strategies, such as those for predicting yields, integrating growing degree hours into management decisions, and for chemical, cultural, or biological controls.

FACTS ABOUT INSECT COLLECTIONS

It is necessary to have collections from specific areas, such as mine sites, and rights-of-way. Insects found in different plant ecosystems may vary as much as the ecotypes. A centralized collection of insects will be useful, but it will not be likely to contain all the insect species that will have to be identified in solving insect problems associated with rangelands, unless specimens from areas of geographical concern are represented in the collection.

An essential step in solving insect problems on rangelands is identification of the insects involved. The taxonomic task is expensive and largely continuous since insects are commonly spread from one area to another. Programs of interdisciplinary range improvement and management need to include funds for insect taxonomy.

The taxonomic classification of the large number of insect species found in rangelands requires a group of specialists, each of whom may specialize in only one or a few small groups of insects. Identification of insect specimens may require months or years because many rangeland insects are little known or yet to be described. (See table 2)

In order to develop reliable management procedures, it is necessary to know an insect's specific name and major details of its biology.

The assistance of those involved in production, management, and utilization of native plants is needed in collecting insects from these plants in different geographical areas. Insects sent for identification, information, or for inclusion in the USU central collection should be properly labeled with specific locations, dates, host plants, kinds and amounts of damage, and sent to the Range Entomologists, Biology Department, UMC 53, Utah State University, Logan, Utah 84322.

OTHER PROBLEMS AND NEEDS RELATED TO ATRIPLEX AND INSECTS

1. We already are aware of a few insects on Atriplex that appear to be having major impacts on the survival of thousands of acres of fourwing saltbush and shadscale, for example, mealybugs. (See fig. 2) Wyoming Mining Companies and the Idaho Road Commission have reported severe defoliation of fourwing saltbush by chrysomelid beetles (Monoxia elegans) and unidentified caseworms in 1983. (See fig. 3)

Figure 2.--Mealybugs are believed to be responsible for the destruction on hundreds of acres of several species of Atriplex. Note a mealybug with its legs exposed, left, and the dorsal view of another on the right. Bodies of mealybugs are usually covered with waxy substances of various diagnostic designs.

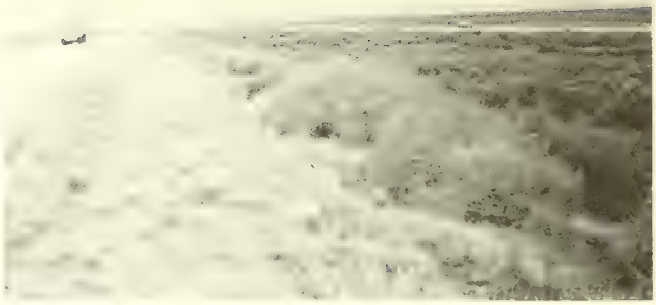

Figure 3.--Top: Atriplex canescens planted in Idaho for roadside rehabilitation was severely damaged in 1983 by a chrysomelid beetle (Monoxia elegans) and an unidentified case-bearing moth. Planting monocultures appears to facilitate insect outbreaks. Bottom: Note pupa of case-bearing moth.

2. There is a need for research and registration of insecticides in order to develop effective controls of native plant insects in greenhouses, on vegetation, in seed being produced, stored, or planted, or on containerized plants and bareroot stock. The legal aspects of applying herbicides on rangelands are well-known to most rangeland managers. There are similar legal restrictions regulating the use of insecticides on rangelands.

In some programs of Atriplex seed production, untested, nonregistered pesticides have been applied regularly, "shot gun" style, to control unknown pests throughout the growing season. These haphazard practices are costly, only partially effective, and ecologically disastrous. For example, some insects develop resistance to insecticides, and plants may become infested with mites that may be more destructive than the original pest insects.

3. Major pests of Atriplex, and their damage, need to be identified, and prioritized for future research.

4. Because of the need for information by commercial enterprises that are planning to establish (or have already established) monocultures of Atriplex, the unique orchards at Ephraim and Nephi, Utah, should be studied by interdisciplinary researchers to obtain basic information comparing seed production of monocultures with that on native rangelands.

5. The cooperation that has begun among state, federal, educational, and private individuals or organizations, needs to continue and increase so that the scope of rangeland research can facilitate the optimal use of Atriplex.

Projects for possible cooperation include: (a) development of methods for producing increased

amounts of high quality seed; (b) development of procedures for processing the seed so that pest insects brought in with the seed are destroyed, and not concentrated at the processing plants or permitted to infest other domestic or native plants; (c) testing ways of protecting stored seed from seed-eating insects; (d) devising methods of fumigating or protecting seed or plants that are sold (from insects originating from processing plant or gathered en route to their destination); (e) determining if application of fungicides or insecticides to seed protects them and increases plant survival in the field.

Solving these problems can reduce costs of range improvement and rehabilitation by increasing success of plant establishment and reducing seeding rates. Customer satisfaction and support of the seed industries is likely to increase if practical recommendations are provided instead of purchases with disclaimer clauses.

6. Seed laboratory personnel have indicated they need new criteria and information to evaluate native plant seeds, formulate standards of classification, and to provide certification of seed purity and germination. Research is needed to solve these problems.

USU studies of caged-injurious insects feeding on native shrub seeds, show that sucking insects that insert their proboscis into the seed may damage vital parts of the seed, presumably by the chemicals they inject and/or by removing materials.

The fed-on seed may be almost full size and appear normal, except for a few discolored spots that may not be noticed by the seed analyst. Some of the damaged seeds show little loss of tissue, and only a small necrotic spot may be visible where the stylets of the insect proboscis entered the plant tissue or seed.

A clip test may show most of the fed-on seed was good. If the insect feeding was in a vital spot in the seed, the seed may not produce a normal plant.

The tasks of seed analysts would be made easier if seeds damaged by caged insects were available to be utilized as examples in classifying seed. Samples of seed shriveled by frost or that is immature should be available for comparison with seed injured by insects.

Damage by chewing insects is usually more obvious and easier to classify than damage by sucking insects. There are many kinds of chewing insects that damage seed--grasshoppers, lepidopterous larvae, adult and immature forms of beetles, and hymenopterans (seed parasites such as chalcids).

Recognizing seeds with live chalcids in them would be helpful to seed buyers because the analysts could recommend that infested seed be treated to prevent the introduction of the seed pests into new areas. (See fig. 1)

Knowing where insect-infested seed comes from, by keeping exact records of purchases, may be helpful to seed producers, collectors, or buyers. The problem of low quality seed may be partially solved if collectors learn to avoid collecting seed in areas that are infested regularly with high populations of injurious insects. (See tables 4 and 5)

CONCLUSIONS

Plant scientists have shown that Atriplex is a valuable plant in many ways for rangeland improvement and rehabilitation of perturbed sites. This review of the status of entomological knowledge related to species of Atriplex suggests that insects are an obstacle to nearly every aspect of this plant's production of vegetation and seed, establishment, and maintenance.

Rangeland insect research at USU at present and for the past few years has concentrated on obtaining a general understanding of the kinds and relative numbers of insects of all plants in rangelands, and getting a broad view of the insects' damage or benefits to range ecosystems (Haws 1982b).

First priority research has been devoted to studies of range grasses and second to bitterbrush, which is a major focus of research at present, but the wide-spread regard for various species of Atriplex shows that these species merit a high priority on the rangeland insect research list.

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USE OF FORAGE SHRUBS IN THE ARID LAND OF CHILE

David Contreras, Patricio Azocar,

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ABSTRACT: Cultivation, overgrazing, and fuelwood removal in the arid IV Region, Coquimbo, Chile, are causing rapid soil degradation and desertification. On those lands where livestock production is now the only feasible land use, Atriplex species are being planted and tested for optimum long-range forage production. It has been found that Atriplex repanda use results in larger lambs and increased milk supply in ewes.

INTRODUCTION

An important area of Chilean rangeland is being affected by a long and strong process of soil degradation and desertification. Approximately 6.9 million acres (2.8 million ha) of dry land make up the arid zone known as IV Region, Coquimbo. In general, relief is dominated by a pattern of alternate valleys and ridges trending east-west, transverse to the dominant longitudinal structure of the Chilean Andes mountains on the east. The coastal range mountains extend on the west, and between the two ranges lies a series of grabens designated as intermediate depressions. The interfluves of these transverse valleys are formed by spurs of the Andes and the coast range.

CLIMATE

The IV Region, Coquimbo, is a mediterranean-type climate. The main disadvantage of the climate, apart from drought and general aridity, is the extreme annual variability in rainfall and the alternation of favorable years with years of serious drought (Di Castri 1968). This area has been defined as having a dry period of 8 to 9 months, 3 or 4 subhumid months in winter, and an absence of cold periods. Droughts lasting 2 to 5 years are not uncommon. La Serena had five serious droughts between 1901 and 1960 (Schneider 1969). Average annual rainfall is so variable that it is difficult to speak of normal rainfall in the IV Region, let alone predict an average. Gasto (1966) calculated that 50.4 percent of the time, the IV Region will have rainfall equal or less than average. Periods of excessive drought have resulted in heavy crop and livestock losses. A period of drought which started in 1967 was responsible for reducing the goat population from 341,000 in 1965 to around 70,000 in 1970 (Aranda 1971). Not only are livestock and natural vegetation losses great during drought, but irrigation water for agriculture activities is scarce, and consequently there are crop losses and damage.

Aridity is a phenomenon of water demand and availability. In the case of the arid land of Chile, water demand by vegetation and crops is high, but availability is restricted by scant rainfall and long dry periods throughout the year. There is a strong belief that the degradation of soil and vegetation in the arid lands has caused decreasing precipitation and drought.

Drought or low rainfall has been named as the main factor responsible for the failure of the systems used to manage agricultural, forest, and range resources. However, it is likely that the present climatic conditions are similar to those found by the Spanish pioneers four centuries ago. A small decrease in average annual precipitation should have had only a very small impact on overall productivity.

VEGETATION

Vegetation, like the topography and climate with which it is so closely associated, varies from north to south and from east to west. Because of the great ecological variability it includes 182 families and nearly 6000 plant species in a pluristratified plant community of trees, shrubs, and annual or perennial range plants. The wild vegetation is mainly low xerophytic scrub, widely scattered columnar cacti, and some evergreen trees. There is a gradual change from widely spaced low shrubs and cacti in the north to a dense mixed-xerophytic and mesophytic chaparral or shrubby formation farther south. This is accompanied by a gradual change in the floristic composition. In most cases, changes in vegetation are less along north-south than along west-east transects, where

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vast ecological changes over short distances are created by differences in relief and elevation. Changes in vegetation along any gradient are a response to elevation, daily sunlight, exposure, soil texture, pH, precipitation, air humidity, graziers, and harvesters.

Floristic components were quite different in the past. The herbaceous strata has been severely affected by cultivation and overgrazing. Many plant species have disappeared or are rare. Dominant plant genera are: Erodium, Vulpia, Oxalis, Plantago, Avena, Calandrina, Cryptantha, Gnaphalium helenium, Koeleria, Adesmia, Pectocaria, and Silene. These are exotic plants introduced from Europe. There are still native range plant species of the genera Trisetobromus, Bromus, Lolium, and Medicago. Some almost extinct species are: Trifolium, Trigonella, Hosakia, Stipa, Nassella, and Festuca. Generally speaking, the process of intensive utilization and mismanagement of natural plant communities, especially during the past 200 years, has resulted in degraded and lower successional climax vegetation on most of the Chilean arid land.

In contrast to popular notions, there is no evidence to suggest that most of the arid land in Chile was forested during prehistoric times. Aside from areas that have been completely cleared, there are sites where endemic shrubs and trees exist, probably with a physiognomy very similar to that encountered by the Spanish pioneers. Most of the areas considered as arid land in Chile are low in biomass production and dependent upon the amount and distribution of precipitation, successional stage, and condition of the vegetation. Average pasture production on arid land is about 1.7 to 3.0 ton/acre (0.7 to 1.2 ton/ha) dry matter per year.

The nutritive value of available forage varies widely through the year and is correlated with the phenology and floristic composition of the plant community. Energy is the second most limiting factor for livestock production and fluctuates between 1.2 and 2.5 k. cal/gr. dry organic matter. Protein content is also a limiting factor, especially during the dry periods. Before the pasture plants bloom their protein content is about 10 to 14 percent; this decreases to 3 to 4 percent after plant dry out. Crude protein can fluctuate from 10 to 30 percent for the same period.

LIVESTOCK

Annual productivity, according to current ecological conditions, allows only the development of extensive grazing operations, mainly goats and sheep. In areas where the degradation is great, farmers raise goat flocks, produce cheese, and sell kids during the spring. Small flocks of sheep are present in areas with high pasture potential along with coastal ranges. Average stocking rate varies from 0.25 to 0.75 head/acre (0.1 to 0.3 head/ha).

Continuous and heavy human pressure on the ecosystem either through wood harvesting, soil cultivation on marginal land, or overgrazing, has produced an accelerated erosion process which in many situations cannot be easily stopped or reversed. Overgrazing has caused an increase in the death rate of palatable plant species along with a decrease in the reseeding rate and recovery rate. On the other hand, nonpalatable plants and weeds have increased growth and population, thus reducing productivity and carrying capacity. Other factors affecting floristic changes were cropping of marginal soils for cereals and other dryland crops such as cumin seed, and harvesting woody plants and trees for domestic purposes.

In order to illustrate how the above-mentioned practices relate to the present state of the coastal terraces, an algorithm (fig. 1) was designed. It suggests the fundamental changes that have occurred in the area (Gasto and Contreras 1979).

The vegetation found in the most degraded areas at the present time consists of plant species belonging to genera Plantago, Dicondra, and Erodium. Periodic plowing eradicated the woody and shrub species, increasing soil erosion and generating retrogressive processes. Plowed soils are fallowed one year before cereals are cultivated. Those species of plants most demanded by animals are often diminished. Sites where soil fertility is depleted are then abandoned and used for goat grazing. The extension of cultivation is always toward places that have been abandoned, generally for more then 20 years. The degraded and abandoned areas are finally invaded by Cassia coquimbensis Vogel (alcaparra); Bahia ambrosioides Lag. (chamisa); Haplopappus angustifolius (D.C.) Reiche (bailahuen), and other plants.

The degradation of the coastal terrace ecosystem began late in the sixteenth century with the introduction of cattle, sheep, and later, goats. The most destructive agents were the introduction of animals resistant to drought, soil cultivation on marginal lands, and harvesting trees and shrubs for firewood. The construction of the Pan American highway through the coastal range in 1950 allowed new access to vast areas, resulting in explosive use of these lands for grain production. The characteristic states of this degradation are shown in figure 1 and can be described as follows:

- climax ecosystem of hemicriptophytes dominated by bunchgrasses such as Nassella chilensis (Trind) Desv.; Pictochaetum stipoides (Trind & Rupr.) Hackd; Stipa plumosa Trin, Stipa lackmophylla Trind and Bromus mollis L.

- reduction of hemicriptophyte biomass.

- invasion of areas by woody shrub plants such as Baccharis concava (R. & Pav.) Pers; Baccharis linearis (R. & Pav.) Pers; Haplopappus anguistifolius (D.C.) Reiche; Trevoa trinervis, Miers.

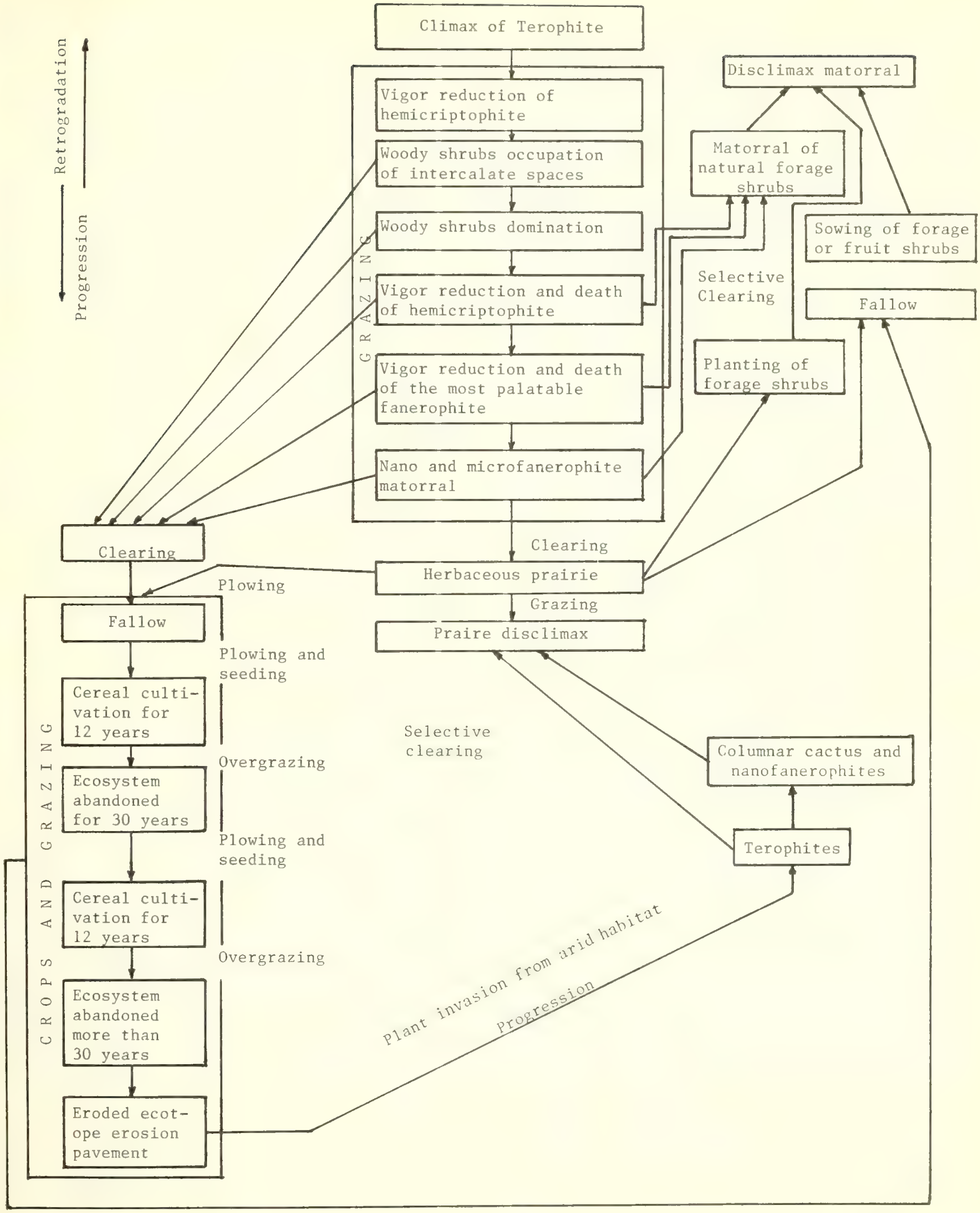

Figure 1.--Scheme diagram of the retrogression of ecosystem in the coastal terrace range, IV Region, Chile. (Gasto and Contreras 1979).

- plowing in successive stages.

- abandoned sites and invasion of cactus species such as Trichocerius chilensis (colla) (Br & R.); Puya chilensis Mol,; and Puya berteroniana Mez.

SHRUB REPLACEMENT

In 1958, the University of Chile, Faculty of Agrarian, Veterinary, and Forestry Science began an evaluation and inspection/search of shrub plant species for livestock forage in a large area of the arid land. The adopted strategy was oriented to suggest species to replace the unpalatable woody shrubs. The most promising native species found from north to south were: Atriplex deserticola Phil.; Atriplex micophylla Phil.; Atriplex atacamensis Phil.; Atriplex coquimbaria Phil.; Chenopodium paniculata Phil.; and Atriplex repanda Phil.

The native Atriplex repanda, also known as "sereno," is a good shrub found in the arid lands of the coastal range. It has a high palatability which almost produced its extinction. It grows year-round and has fast regrowth in summer, minimal growth in late fall and winter. Nutritive value is high. Protein content is 18-20 percent in leaves, 11-12 percent in stems, and 9 percent in seeds. The average crude fiber content is 23 percent. Characteristics of "sereno" include: high resistance to dry conditions, green forage and protein availability during the dry period, and high palatability.

Low seed germination was found in Atriplex repanda. Germination was less than 5 percent under natural conditions. Soaking seeds in sulfuric acid was observed to improve seed germination up to 35 percent. The results indicate that seed age has an important role in seed germination. One-year-old seeds need 7 hours soaking, while 5-year-old seeds need only 2 hours soaking (Olivares and Johnston 1978).

SHRUB-LIVESTOCK STUDIES

Studies were conducted to compare grazing intensity. A grazing trial was oriented to evaluate when and how many times shrubs should be grazed in order to get the best response in terms of plant longevity. Results indicate that the shrub Atriplex repanda could be grazed any time of the year, but only once for maximum productivity and longevity. When grazed twice a year, forage production is high but plants are affected; vigor, regrowth, and population density are reduced (Di Marco 1973).

Another problem in introducing Atriplex repanda is timing the integration of this supplementary forage into the annual cycle of livestock. It has been seen that pregnant ewes perform better when they graze on repanda during the last third of their gestation period. Lambs are born with greater weight. Growth also is faster, indicating an effect on milk lactation (Rodriguez and Gasto 1972; Duchens and Cuneo 1980) (Tables 1,2,3).

Table 1.--Percentage of ewes giving birth in two different pasture types, 1972 (Rodriquez and Gasto 1972).

Type of pasture	Births: Single	Births: Double (twins)	Total of ewes lambing
	Percent		
Shrubs	61.7	32.3	94.0
Prairie	76.4	11.7	88.0

Table 2.--Average lamb weight by pasture type and carrying capacity, from birth to 4 months old (Duchens and Cuneo 1980).

	Lamb weight: Birth	1st month	2nd month	3rd month	4th month
	Kg				
Type of pasture					
Pasture	4.1	8.7	15.4	23.9	31.1
Shrub	4.6	8.7	15.6	23.7	32.2
Carrying capacity					
0.5 sheep/ha/year	4.7	10.1	16.3	24.3	31.6
2.0 sheep/ha/year	4.0	8.4	14.7	23.2	31.7

CONCLUSIONS

After 15 years of research and studies it can be concluded that it is possible to replace some of the nonpalatable floristic components of the natural dry land ecosystem in Chile with shrubs such as Atriplex repanda and Atriplex nummularia without altering the structure and functioning of the ecosystem. Restricted management of the shrub species produces improved herbaceous pasture.

As a result of these studies, the National Forest Corporation (CONAF) has started a plantation program in the arid coastal range of Chile (IV region, Coquimbo) in cooperation with private entities. During 1976, 63.5 acres (25.7 ha) were planted. Large amounts of money have been invested by CONAF and land owners for forage shrubs to ensure green forage during critical periods (fig. 2,3).

Table 3.--Associated effects on sheep weight of pasture type, carrying capacity, and birth type (Duchens and Cuneo 1980).

		Sheep weight					
		Initial	Birth	1st. Mo.	2nd Mo.	3rd. Mo.	4th. Mo.
		- - - - - -	- - - - - -	- - - - kg	- - - - - -	- - - - - -	- - - - - -
Type of pasture	Carrying capacity						
Shrub	0.5 sheep/ha/yr	59.3	58.1	53.3	55.7	59.8	62.6
Pasture	0.5 " " "	59.4	53.6	50.8	55.8	59.5	62.1
Shrub	2.0 " " "	59.7	52.2	51.5	53.9	59.3	66.5
Pasture	2.0 " " "	58.9	48.8	47.9	52.1	59.1	63.2
Type of pasture	Birth						
Shrub	One	--	57.6	53.6	56.2	60.2	63.6
Pasture	One	--	52.6	51.1	55.5	61.2	63.6
Shrub	Twins	--	52.8	51.2	53.4	59.0	65.5
Pasture	Twins	--	49.8	47.6	52.3	57.4	61.7
Carrying capacity	Birth						
0.5 sheep/ha/yr	One	--	57.0	53.6	58.1	62.3	64.9
2.0 " " "	One	--	53.2	51.0	53.7	59.0	62.3
0.5 " " "	Twins	--	54.7	50.0	53.5	57.0	59.8
2.0 " " "	Twins	--	47.8	48.4	52.3	59.4	67.4

(A) (B)

Figure 2.--Shrub plantation in the IV Region, Coquimbo, under the National Forest Corporation Program 1976-83. (A) Slopes denuded by crops and overgrazing by goats, (B) contour furrows planted with 2-year-old shrubs.

Figure 3.--Six-year-old plantation of Atriplex nummularia grazed by goats in the arid IV Region, Coquimbo.

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Section 7. Revegetation

PERFORMANCE TESTS OF FOURWING SALTBUSH TRANSPLANTS IN EASTERN OREGON[1]

J. Michael Geist and Paul J. Edgerton

ABSTRACT: Recent steps have been taken toward improving the diversity and abundance of forage for livestock and big game on historically depleted foothill ranges in eastern Oregon. Fourwing saltbush (Atriplex canescens [Pursh] Nutt.) is being evaluated for a potential role in this effort. The results have been positive and encouraging.

The adaptability of 3 seed sources of this species was observed for 5 years in a uniform garden setting. 'Rincon' fourwing saltbush, a New Mexico source, performed best. Subsequent tests using 'Rincon' transplants were conducted to evaluate adaptability to various sites under different conditions of competition control. Survival was enhanced by competition control in one experiment but not in a second. First season average height growth of spring transplants was doubled with competition control, was nearly double at the end of 2 seasons, and average plant weight was 4 to 10 times greater with competition control after 2 seasons. All results indicate a high potential for the use of 'Rincon' fourwing saltbush in rehabilitation of these ranges.

INTRODUCTION

As with many areas of the Western United States, eastern Oregon rangelands could benefit from diversified and increased food supplies for wild and domestic ungulates. Greater diversity in vegetation can improve seasonal forage quality and may even contribute to greater vegetative stability (Margalef 1969). This paper reviews efforts in pursuit of such benefits on shrub-steppe ranges in eastern Oregon. This research is somewhat restricted in scope, but we believe it has broader applicability and should help both public and private land managers with their resource decision-making.

These depleted Oregon ranges are generally dominated by less desirable forage plants such as cheatgrass brome (Bromus tectorum L.), medusahead wildrye (Elymus caput var. medusae L.), Japanese brome (Bromus japonicus Thunb.), various subspecies of big sagebrush (Artemisia tridentata Nutt.), rabbitbrush (Chrysothamnus spp. Nutt.), and a variety of forbs. Some ranges have been successfully seeded to domestic grasses, usually crested wheatgrass (Agropyron desertorum Schult.), to increase available forage and reduce grazing pressures on remnants of preferred native perennial plants. However, such seedings commonly lack a suitable variety of forage or wildlife cover. The purpose of our research is to provide knowledge about opportunities to improve these less desirable rangeland conditions.

The Keating range in Baker County, Oreg., is typical of foothill areas where vegetation improvement has been a long standing concern. It includes 45,000 acres (18 218 ha) of crucial deer winter range containing a mosaic of depleted sites and extensive grass seedings. Winters are cold and windy, summers are hot with a pronounced July-August drought. Precipitation occurs mostly in winter and spring, principally as snow. Fall precipitation is unpredictable but sometimes significant. Annual precipitation is variable, but at our study sites averages about 12 inches (30 cm). Mule deer winter on the range from December through March. Livestock, mostly cattle, graze in a variety of management systems, generally from mid-April to late July. Livestock may return between November and January depending on the annual production and whether fall precipitation stimulates late regrowth. Our study sites occur within the crucial winter range area.

We have been determining the potential of fourwing saltbush (Atriplex canescens [Pursh] Nutt.) for foothill range improvement. It is widely recognized in the Western United States as a valuable shrub to be included in rangeland plantings on a

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variety of ecological sites (Plummer and others 1966; Springfield 1970).

The results of 3 related experiments are reported. (1) An adaptability trial begun in 1976 to screen 3 fourwing saltbush accessions in a uniform garden, (2) an establishment trial begun in 1981 to compare site preparations at the same location utilizing the most promising of the above 3 accessions, and (3) an adaptability/establishment trial begun in 1982 with the same accession as in (2) to compare site preparations and performance over a broad portion of the Keating range.

INITIAL ADAPTABILITY TRIAL

Thirty individuals from 3 sources were transplanted into a 6-ft (1.8-m) grid in the Keating uniform shrub garden in the spring of 1976. The 3 sources were: Decker, Mont., a relatively high-elevation, cool, moist location; Moreno Valley, Calif., a low-elevation, dry, hot location; and Rincon Blanco, N. Mex., a relatively high-elevation, cool, moist location. The Decker source was known to exhibit a more prostrate growth form. Plants were obtained from the USDA Forest Service, Intermountain Forest and Range Experiment Station, Shrub Sciences Laboratory, Provo, Utah.

The New Mexico source has been evaluated by researchers and land managers in plantings and seedings on a variety of sites in the Intermountain West (McArthur and others 1983). Its superior adaptability and performance as a forage and reclamation plant has merited plant selection and seed release by the USDA and cooperating agencies for commercial production and marketing of seed and plants (McArthur and others 1982). The selection has been released under the name 'Rincon' fourwing saltbush. We used the 'Rincon' selection in our trials.

The garden area is protected by a deer-proof fence. The site was initially moldboard plowed and disced just prior to planting, and has been annually cultivated since. Standing vegetation was an established crested wheatgrass seeding, but nearby unseeded range suggests the area prior to seeding was a basin big sagebrush/cheatgrass brome/weedy forb stand with scattered rabbitbrush. Soils are deep with silt loam surface texture grading to clay loams in lower horizons and then to weathered granitic materials of coarse sand and gravel size. The soil parent material is dominantly granitic outwash, but apparently was surface influenced by silt-sized volcanic ash of unknown origin. The outwash material extended beyond 5 ft (1.5 m) deep. No irrigation water or fertilizer was applied.

Plants were measured in the fall of each year for maximum height growth and crown spread and assessed for survival. Green weight estimates were made to provide an additional comparison of plant sizes.

Statistical comparisons were not made because this was a case history. We have presented only means and standard deviations of the plant parameters measured.

Results of Adaptability Trial

Ideal conditions afforded by cultivation, protection from ungulate browsing, and deep soils yielded excellent survival (93-100 percent) over the 5-year period. Average height and crown spread of the California and New Mexico sources were very similar, and both were about 2 times the size of the prostrate form obtained from Montana (table 1). Green weight estimates indicated the average growth rate of the New Mexico source was greater than the California source which, in turn, outgrew the Montana source. Both the New Mexico and California sources showed indications of being fast starters which is important in relation to the dry period in the summer. Only the Montana plants flowered the first year (about 53 percent). All sources flowered at about 50 percent in year 2 and 86 percent or more in ensuing years.

In follow-up evaluations it was decided to use only 1 source. Given the widespread success of the New Mexico source and the excellent local performance we observed, it was chosen for further evaluations described below.

ESTABLISHMENT TRIAL

Knowledge about the benefits of competition control to plant establishment was considered necessary in preparation for future tests of outplanting success. Thus, the effects of 3 site preparation treatments on the growth and survival of 'Rincon' fourwing saltbush were compared in the Keating garden exclosure. Treatments were: no preparation (control), spot scalp, and spot spray. Three replicates of the treatments were assigned in a completely random fashion to nine 18- by 66-ft (5.5- by 20.1-m) plots containing 30 transplants each. Transplants were made on a 6- by 6-ft (1.8-by 1.8-m) grid spacing within plots. Treatment spots were approximately 3 ft (1 m) square; scalps were about 1 inch (2.5 cm) deep. Roundup herbicide was applied to the foliar wetting point with 2 passes from a backpack sprayer at a concentration of 4 fluid oz (118 ml) of herbicide concentrate (1.64 oz [48 ml] active ingredient) and 2 oz (59 ml) of No Foam B sticker per gallon (3.8 l) of water. Scalping and planting were done in late April 1981, 2 days after

Table 1.--Fourwing saltbush source comparisons at the Keating Uniform Garden over a 5-year period. Data are means from about 30 plants.

State	1976	1977	1978	1980
	Maximum height - means (standard deviations), inches			
Montana	9 (4)	18 (3)	20 (4)	20 (5)
California	25 (5)	35 (5)	41 (6)	46 (9)
New Mexico	25 (6)	35 (4)	42 (6)	49 (7)
	Maximum crown spread - means (standard deviations), inches			
	1976	1977	1978	1980
Montana	23 (13)	40 (8)	46 (10)	43 (12)
California	46 (16)	64 (13)	76 (18)	81 (17)
New Mexico	40 (14)	58 (12)	76 (17)	89 (19)
	Estimated green weight - means (standard deviations), pounds			
	1976	1977	1978	1980
Montana	0.4 (0.4)	1.0 (0.6)	2.0 (1.3)	2.8 (2.5)
California	1.2 (0.8)	3.1 (1.3)	9.9 (5.7)	8.1 (3.7)
New Mexico	1.2 (0.8)	4.7 (3.0)	11.8 (6.5)	12.5 (10.6)

spraying. All operations were done by hand in a single day. Soils were moist at that time. Seedlings of target annual grass and weed species were approximately 1 inch (3 cm) high.

Plants were checked for survival and maximum height measured in the fall each year. Layered canopy cover estimates were made prior to spraying and at the end of the second season on center rows of plots by the method of Daubenmire (1959). Plants were harvested 2 years later at the end of September 1983 for production comparisons. They were clipped at ground level, ovendried at 131°F (55°C) and weighed. Mean values reported for height and weight were computed on the basis of live plants only.

The results were tested by one-way analysis of variance and Scheffe's test of means at the 95 percent level of confidence (Freese 1967).

Results of the Establishment Trial

Data from 2 growing seasons indicate survival percentages of plants on the control plots were about one-half, height (maximum) growth was one-half or less, and dry weight was much less when compared to plants on the other treatment plots (table 2). The height of spray treatment plants exceeded that of scalp treatment plants after the first season, but not the second. Spray treatment plants substantially exceeded scalp treatment plants in top weight after 2 growing seasons. There was relatively little change in survival from the first to the second season. Plants in this trial grew slower than those in the adaptability trial noted above. We suspect this was mostly because of decreased competition through cultivation of weeds in the adaptability trial; however, differences in climatic factors from prior years may also have contributed.

Competition was essentially controlled by spraying or scalping the season of treatment, but reinvasion was evident by the end of season 2 (table 3). Canopy coverage of herbaceous vegetation that invaded scalp and spray spots was commonly little different from control spots. This indicates a limited time effectiveness of competition treatments.

Table 2.--Comparison of fourwing saltbush transplants of the New Mexico source over 2 growing seasons, under 3 site preparations, in the Keating garden exclosure. Values for height and weight are means of the survivors from the 90 transplanted seedlings.

Characteristic		Control	Scalp	Spray
Survival (%)	- 1981	43a[1]	99b	87b
	- 1982	37a	87b	86b
Height (inch)	- 1981	6a	12b	17c
	- 1982	15a	21b	29b
Dry weight (oz)	- 1982	0.6a	2.6b	6.7c

[1] Mean values in the same line followed by different letters are significantly different ($P < 0.05$).

Table 3.--Percentages of layered canopy cover[1] at the end of the second growing season (1982) for the Keating Garden establishment trial.

	Vegetation class				
Treatment	Overall	Annual grass	Perennial grass	Forbs	Planted shrubs
Control	95	72	12	61	2
Spray	89	57	0	59	27
Scalp	80	46	2	54	17

[1] Layered canopy cover can exceed 100 percent when values for individual species or species groups are summed; however, the vertical overlapping of layers of foliage precludes our ability to simply add or subtract these values. We did not obtain an overall layered canopy cover ignoring the planted shrubs and this is a regrettable oversight because we found this of interest later. We felt this might be more reflective of competition control.

ADAPTABILITY/ESTABLISHMENT TRIALS

The first step in gathering data on the general outplanting performance of fourwing saltbush was taken with trials begun in April 1982. These trials included 5 locations at which the New Mexico accession was planted into an unsprayed (control) plot and into spots sprayed with Roundup herbicide. Treatment plots contained 75 plants arranged in 5 rows and spaced on 6-ft (1.8-m) centers. The 2 randomly assigned treatments were placed side by side and were replicated at 5 locations spanning a sizable portion of the Keating range. Experimental design was, thus, a randomized block with locations representing blocks. The spray spot remained the same size and application rate was also the same as used in the previous establishment trial. Four of the 5 locations were fenced from cattle grazing, but all were accessible to deer. Some protection from livestock use at the fifth location was afforded by a single-strand, 3-sided barbed wire barricade used to divert off-road vehicle traffic. Plant performance was measured and calculated as in the adaptability trial after 1 growing season in late September 1982. Degree of exposure to wild animal use is unknown.

Site factors associated with locations afforded a variety of soil and vegetative conditions under which to test performance of transplants (table 4). Some were recently disturbed, others had been disturbed by some previous management practice including seeding, but documented histories for the areas are lacking. Soil surveys are being conducted in the general area, but no correlated classifications are available.

Table 4.--General characteristics of sites associated with initial outplanting of fourwing saltbush on the Keating range in Baker County, Oreg.

Location	Elevation	Slope	Aspect	Vegetation supported	Soil
	Feet	Percent	Degrees		
Ritter	2920	4	125	*Agropyron desertorum* *Artemisia tridentata*	Moderately deep; surface texture - loam to silt loam
Tucker	3018	6	186	*Bromus tectorum* *Amsinckia* spp. *Erodium cicutarium*	Shallow to moderately deep; surface texture - clay loam; swelling
Lowar	2759	8	133	*Bromus tectorum* *Cardaria* spp.	Deep; silt loam surface and subsurface texture; volcanic ash parent material
Smallex	3159	17	240	*Bromus tectorum* *Elymus caput-medusae* *Sisymbrium* spp.	Moderately deep mixed outwash of mainly granitic origin; surface texture - loam
Hollow	3041	14	84	*Elymus caput-medusae* *Sisymbrium* spp.	Moderately deep to deep; surface texture - clay loam; swelling

Containers having 10.5-inch^3 (175-cc) cells were used to produce the transplants for the 5 pairs of treatment plots. In addition, at only the Hollow location, 2 sets of 25 transplants grown in 21.5-inch^3 (350-cc) containers were used to determine whether larger containers held any advantage over smaller containers. A randomly predetermined subset of two 25-plant blocks in the smaller container planting was used for comparison with the same number of larger container transplants. The Hollow location was chosen because it was thought to be an especially difficult revegetation situation.

Statistical tests used were analyses of variance and Scheffe's test of means with significance determined using a 5 percent significance level.

Results of the Adaptability/Establishment Trial

Site preparation by spraying did not significantly affect survival over all plots, but spraying markedly affected height growth (table 5). Had standing crops been sampled, the differences reflected by dry weights would have been even greater. As in the trial discussed above, plants in the unsprayed plots were frequently healthy though relatively small; their vigorous appearance indicated they would likely survive the ensuing winter. The poorest survival among the 5 locations was 55 percent without spraying and 75 percent with spraying.

Plant competition along the edges of the spray spots grew better in response to competition control. Thus, spraying in itself produces structural changes in adjoining vegetation. Spraying was lethal to all plants contacted, and we found complete kill of a sagebrush plant required full and thorough coverage of the plant canopy.

Data from the container comparison conducted at the Hollow site were similar to overall trends. No differences were found in survival (ranged from 88 to 100 percent), but growth was greater where competing vegetation was reduced by spraying. In addition, a

significant ($P < 0.05$) interaction was detected between spray and container treatments. Transplants from larger containers grew taller in the control plots, but the mean heights of plants from the 2 container sizes were nearly identical in sprayed plots. Smaller container plants grew more in response to competition control (table 6).

Table 5.--Fourwing saltbrush transplant performance averaged over 5 locations after 1 growing season. Values for height are the overall means of survivors from 375 seedlings transplanted per treatment.

Characteristic	Control	Spray
Survival (%)	78a[1]	88a
Height (inches)	6a	14b

[1]Mean values in the same line followed by different letters are significantly different ($P < 0.05$).

Table 6.--Mean values of maximum height of fourwing saltbush transplants in the container size comparison trial at the Hollow site after 1 growing season, 1982.

Container size	Control	Spray
	--------inches----------	
Small (175 cc)	5	12
Large (350 cc)	8	12

DISCUSSION AND CONCLUSIONS

The excellent performance of fourwing saltbush suggests this species could play a significant role in upgrading problem areas of the Keating range. Widespread establishment of this plant could benefit livestock and big game forage supply and provide cover for upland game birds and possibly other nongame species.

Competition control seems to be necessary to assure vegetation improvement on these ranges. This finding is similar to those of other researchers (Holmgren 1956; Hubbard 1957). Control likely will benefit growth and in some years may also promote increased survival of container stock. Presuming environmental compatibility of herbicide treatment, we would recommend this practice over scalping because of time and labor advantages. Roundup herbicide only controls, however, vegetation growing at the time of application. Carryover effects the second season may occur, but the extent is unpredictable. Reinvasion of spray spots invariably occurred in the second season. Spray spots retained litter cover as an evaporative and thermal barrier and litter also helped soil erosion resistance. Nutrient-rich topsoil remained in place with spraying also. Scalped spots seemed to have no advantage over sprayed spots. Scalp depth was hard to control and scalping was more time consuming.

Rapid growth exhibited by the 'Rincon' plants in our experiments is an especially desirable characteristic for establishment on northwest rangelands with low growing season precipitation. Rapid growth is essential to take advantage of available stored soil moisture before evaporative losses occur.

Our work with 'Rincon' saltbush suggests the adaptability of this shrub is widespread and excellent. Extensive transplanting may not be a feasible management alternative, so future research should concentrate on evaluating other establishment practices to facilitate the use of this promising shrub.

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NURSERY PROPAGATION AND OUTPLANTING OF BAREROOT CHENOPOD SEEDLINGS

Nancy Shaw and Stephen B. Monsen

ABSTRACT: Cultural practices for growing bareroot chenopod transplant stock and results of two outplanting trials are discussed. Acceptable seedlings of several species can be propagated, but erratic seed germination and morphological characteristics of the seedlings can create production problems. Additional work is required to refine techniques for growing each species. Bareroot stock of fourwing saltbush (Atriplex canescens [Pursh] Nutt.), winterfat (Ceratoides lanata [Pursh] J.T. Howell), and several other shrub and forb species were successfully intertransplanted into a crested wheatgrass stand using a mechanical treeplanter. Excellent survival of adapted species and adequate control of competition were attained with this technique.

INTRODUCTION

Disturbances of arid shrublands result from natural events and the increasing impacts of human activity. Natural recovery proceeds slowly and seeding in areas that receive less than 10 inches (25 cm) annual precipitation is risky (Bleak and others 1965; Holmgren 1973). Depending upon planting objectives and financial considerations, transplanting may be employed to more rapidly and reliably restore native species, initiate processes such as litter accumulation and nutrient cycling, stabilize erodible soils, increase forage production, provide wildlife habitat, and meet legal requirements for reclamation. Transplants are usually more tolerant of drought, competition, salinity, soil crusting, predation by rodents or big game, late frosts, and other adverse conditions than are newly emerged seedlings and may be used to minimize or avoid these and other problems associated with direct seeding (McKell and Van Epps 1981; Ferguson and Frischknecht 1981; Stevens and others 1981b).

Shrubby chenopods dominate salt-desert shrublands and are widespread on rangelands of the Western United States. Seed and transplant stock of adapted chenopods have been used for the reclamation of areas disturbed by mining (DePuit and Coenenberg 1979; Aldon 1981; Ferguson and Frischknecht 1981). Transplants may also be used to restore restricted rangeland sites such as holding or trailing areas, intermittent waterways, and portions of critical winter ranges that are difficult to seed or inaccessible to seeding equipment. Fourwing saltbush (Atriplex canescens [Pursh] Nutt.), winterfat (Ceratoides lanata [Pursh] J.T. Howell), and other chenopods have been propagated as low water use ornamentals for landscaping projects, roadways, campgrounds, and recreation areas on arid lands (Stark 1966; Steger and Beck 1973). Intertransplanting or interseeding Fairway crested wheatgrass (Agropyron cristatum [L.] Gaertn.) and standard crested wheatgrass (Agropyron desertorum [Fisch.] Schult.) stands with fourwing saltbush has increased forage production and improved the quality and diversity of cover for livestock and wildlife (Monsen 1980; Bjugstad and others 1981; Stevens and others 1981b; Rumbaugh and others 1982). In southern California, fourwing saltbush and quailbush (Atriplex lentiformis [Torr.] Wats.) have been established by seeding and transplanting to provide cover for upland game birds (California Department of Fish and Game 1968; McKibben and Slayback 1977).

To date, chenopod transplants have largely been produced in containers in greenhouses. Container seedlings of fourwing saltbush and other Atriplex species have been successfully propagated from seed or cuttings (Aldon 1970; Wiesner and Johnson 1977). Greenhouse propagation of winterfat has proven to be more difficult. Although the production of bareroot stock presents a number of problems, limited experience at the Lucky Peak Nursery, near Boise, Idaho, indicates that adequate stock of several species including fourwing saltbush, Gardner saltbush (Atriplex gardneri [Moq.] D. Dietr.), shadscale (A. confertifolia [Torr. & Frem.] Wats.), and winterfat may be produced at this site. Spiny hopsage (Grayia spinosa [Hook.] Moq.) and greasewood (Sarcobatus vermiculatus [Hook.] Torr.) seedlings have generally been of marginal quality. This paper will present an overview of problems and solutions associated with nursery propagation and outplanting of these species.

NURSERY PROPAGATION OF CHENOPOD SEEDLINGS

Seed

Named varieties of four chenopods have been released for commercial seed production by the U.S. Department of Agriculture, Soil Conservation Service, and cooperating agencies

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(table 1). Quality of seed produced under agricultural conditions should become superior to that of wildland collections as appropriate cultural practices are developed. Additional sources of seed include collections from selected populations grown at a nursery, collections from selected wildland stands, or purchases from commercial dealers. Seed transfer guidelines have not been established for chenopod species. For contract production, seed sources known to be adapted to the planting site must be obtained.

Seed must be carefully cleaned to obtain high purity levels, insure even flow through the drill, and maximize uniformity of seed placement and subsequent seedling development in the nursery bed. Purity of purchased seed may be adequate for rangeland seedings, but further cleaning may be required for nursery plantings. Seed produced in wildland stands frequently contains a high precentage of empty utricles, some of which can be removed by flotation or air separation. Fourwing saltbush, Gardner saltbush, greasewood, and spiny hopsage seeds are normally cleaned by hammermilling to remove appendages from the utricles (table 2) and fanning to remove trash. Although Springfield (1970) found that hammermilling fourwing saltbush fractures the utricle and improves germination, Smith and Martinez[1] determined that shadscale germination was not improved by this process. Booth (1983) reported that the fluffy hairs of winterfat utricles cling to the soil surface and guide the radicle into the soil. Hammermilling to separate the utricles from the seed and simplify seeding not only removed these hairs but frequently damaged the embryonic rootcap.

Optimum storage conditions and the effects of various storage regimes on seed quality and duration of seed viability have not been determined for most chenopods. Fourwing saltbush, shadscale, and Gardner saltbush seedlots have been safely stored under open, dry conditions for at least 5 years. Duration of viability, especially for Gardner saltbush, may vary widely among seedlots (Plummer and others 1968; Springfield 1968; Foiles 1974). Stevens and others (1981a) found seed of fourwing saltbush viable after 15 years of open, dry storage while winterfat seed viability declined rapidly after only 2 years. Springfield (1974b) succeeded in maintaining winterfat viability for 8 years by placing the seeds in cold, dry storage at 32° to 44° F (0° to 7° C).

Results of purity and germination or viability tests are used to provide an estimate of seed quality and are used in computing seeding rates. Purity and seed weights are obtained following standardized procedures (AOSA 1981). Association of Official Seed Analysts standards for testing the germination of chenopods and other native shrubs have not been established. Consequently, seed laboratories must develop or adopt procedures for each species. In addition, individual populations vary in germination requirements (Workman and West 1967; Clark and West 1971). As a result, tetrazolium chloride tests of seed viability are frequently substituted for germination tests. These tests are quickly completed and results are more consistent than those of germination tests.

Seed of most species matures in the fall (Plummer and others 1968; Eddleman 1977), and requires one to several months of afterripening in storage prior to planting (Springfield 1972; Foiles 1974). Although they vary greatly in size, seed of Atriplex species may be planted at rather precise spacings and depths with the Love-Oyjord or similar nursery drill. Seed is covered lightly with sand and may be mulched to improve moisture retention near the soil surface during germination and seedling emergence. Winterfat seed is not free flowing and cannot be metered through most drills. Seed is hand planted in shallow drill furrows or broadcast seeded on nursery beds formed with a roller or imprinter. Seed is covered by driving an imprinter over it. Winterfat seeds tend to cling together and cannot be effectively covered with a drag. Seed spacing has also been regulated by planting seeds encased in seed tapes.

Optimum seeding densities have not been established for nursery production. Estimates are based on experience with a limited number of seedlots. Fourwing saltbush and winterfat grow rapidly and are normally lifted as 1-0 stock (Ferguson and Monsen 1974). Target densities are 15 to 20 seedlings/ft^2 (161 to 215/m^2). Shadscale and Gardner saltbush grow more slowly and may be sown at higher densities (25 seedlings/ft^2 [269/m^2]). Depending on their growth rates, they may be lifted as 1-0 or 2-0 stock.

The amount of seed required to produce a requested number of seedlings may only be estimated. Culling rates and seedbed mortality figures have not been established at individual nursery sites as too few seedlots have been grown to provide adequate data. Although extreme variability occurs between seedlots, a seedbed mortality rate of 40 percent and culling rate of 20 percent are used in computing seeding rates at the Lucky Peak Nursery.

Nursery Practices

Cultural requirements have not been developed. Practices in use include a combination of propagation techniques used for conifers and hardwood trees and shrubs modified through onsite experience and observations and measurements of seedling development, growth rates, and morphological characteristics of individual species.

[1]Smith, B.; Martinez, E. S. Germination requirements and allelopathic characteristics of [illegible]ale (Atriplex confertifolia). Unpublished draft provided to authors; 1983.

Table 1.--Chenopod cultivars cooperatively released by the U.S. Department of Agriculture, Soil Conservation Service[1].

Scientific name	Cultivar	Common name
Atriplex canescens	Rincon	Fourwing saltbush
Atriplex canescens	Marana	Fourwing saltbush
Atriplex canescens var. *aptera*	Wytana	Fourwing saltbush
Atriplex lentiformis	Casa	Quailbush
Atriplex semibaccata	Corto	Australian saltbush
Kochia prostrata	Immigrant	Forage kochia

[1]U.S. Department of Agriculture, Soil Conservation Service, 1982.

Table 2.--Propagation of chenopods as bareroot seedlings.

	Fourwing saltbush	Winterfat	Gardner saltbush	Shadscale	References
Seed collection dates	10/20-3/1	9/25-11/25	9/10-3/1	10/15-3/1	1
Seed cleaning	Dry, hammermill (1,500 rpm with 0.25-inch wire mesh), fanning mill.	Dry. Screen to remove twigs. Separate small debris with air blower.	Dry, fanning mill.	Dry, hammermill, fanning mill.	1, 2 3, 4, 5
Acceptable purity (percent)	95	50	90	95	1
Acceptable germination (percent)	50	85	45	35	1
Storage requirements	Open, dry, fumigate.	Open, dry or dry, cold (34°-42° F) in sealed containers.	Open, dry, fumigate.	Open, dry, fumigate.	1, 5 7, 8, 9
Duration of seed viability (years)	16+	0-3 (open storage) 8 (cold storage)	5	16+	2, 5, 6
Presowing treatment	10 months after-ripening.	9-13 weeks after-ripening.	3 months afterripening.	6-12 months afterripening.	5, 10, 11, 12, 18
No. seeds/pound cleaned seed	13,000-148,000	126,000-210,000	111,450	29,500-126,000	2, 5, 13
Seedbed mortality (percent)	40	40	40	40	14
Culling rate	20	20	20	20	14
Seedbed density (seedlings/ft^2)	15-20	15-20	25	25	14

Table 2.--(con.)

	Fourwing saltbush	Winterfat	Gardner saltbush	Shadscale	References
Sowing date	Fall, spring	Spring, (fall)	Fall, spring	Fall, spring	
Sowing method	Drill	Hand seed in drill furrows and cover lightly. Broadcast on firm surface. Cover lightly using imprinting implement.	Drill	Drill	
Sowing depth (inches)	0.50	<0.25	Near surface	0.50	5, 11, 15 16, 17, 19
Pruning:					
Top	Yes	No	No	No	
Root	Yes	No	No	No	
Lifting considerations	Brittle shoots, thick taproot, rigid lateral roots.	Woody shoots, thick taproot.	Woody branches decumbent at base.	Brittle shoots. Spinose branches. Thick taproot.	
Production period	1-0	1-0	1-0, 2-0	1-0, 2-0	14
Persistent leaves	Yes	Yes	Yes	Yes	
Vegetative propagation	Wildings, stem cuttings	Wildings	Wildings	Wildings	18
Special considerations	Seedlings susceptible to late frosts, damping off. Treat seed with fungicide.	Seedlings susceptible to late frost.	Seedlings susceptible to damping off. Treat seed with fungicides.	Erratic germination. Low growth rate.	3, 5

1. Jorgenson, K. R.; Stevens, R. Ephraim, UT: Data on file at Great Basin Experimental Area; 1982.
2. Plummer and others 1968.
3. Wasser 1982.
4. Booth 1983.
5. Foiles 1974.
6. Stevens and others 1981a.
7. Workman and West 1967.
8. Springfield 1974b.
9. Springfield 1968.
10. Springfield 1972.
11. Stevens and others 1977.
12. Springfield 1969.
13. Eddleman 1977.
14. Lucky Peak Nursery, Boise, ID: Data on file at Lucky Peak Nursery; 1975-1983.
15. Springfield 1974a.
16. Springfield 1971.
17. Nord and others 1971.
18. Wiesner and Johnson 1977.
19. Smith, B.; Martinez E. S. Germination requirements and allelopathic characteristics of shadscale (*Atriplex confertifolia*). Unpublished draft provided to authors; 1983.

Irrigation regimes have not been developed for individual species. Once established, arid land species require less irrigation than species from more mesic sites. However, logistics may prevent the use of specialized watering regimes for small seedling lots in the nursery. Throughout the germination period it is essential that the soil surface be kept moist. This is particularly important for winterfat and Gardner saltbush, which are sown near the soil surface, and for seedlots with low germination rates and long germination periods. This problem may be alleviated by mulching. Fourwing saltbush and Gardner saltbush are susceptible to damping off, particularly under cool, moist conditions. Seeds may be pretreated with Captan. If seedling mortality is noted, water should be applied only sparingly.

Soil fumigants may be applied to nursery beds prior to seeding to reduce weed problems, however, poor seed germination and erratic growth have been noted in midwestern nurseries when shrub species were seeded in fields fumigated with methyl bromide. Problems were attributed to decreased endomycorrhizal spores in the soil and endomycorrhizal development on seedlings (Riffle 1980). The use of fumigants such as Mylone that eliminate root pathogens, but are not harmful to mycorrhizal fungi, was recommended. Williams and others (1974) found growth of fourwing saltbush seedlings in the greenhouse to be enhanced by the presence of vesicular-arbuscular endomycorrhizae. Transplanting success has been improved by inoculating fourwing seedlings with Glomus mosseae Nicol. and Gerd. (Aldon 1975).

Most native shrub seedlings are weeded mechanically or by hand because herbicide recommendations are not available for individual species. Promising herbicide treatments must be tested on trial plots of individual species at the nursery site before large scale application is attempted (Sandquist and others 1981).

Chenopods are generally faster growing and less demanding of nutrients than conifers. Nitrogen applications are usually necessary, particularly if high carbon-nitrogen ratios develop as a result of mulching. Conifers and shrubs normally receive similar fertilizer treatments at the Lucky Peak Nursery. Two thousand pounds of 6-2-0 Milorganite (2 245 kg/ha) is incorporated into the soil prior to sowing. Ammonium nitrate (34-0-0) and superphosphate (0-46-0) are applied as side dressings.

Fourwing saltbush grows rapidly, producing a highly branched shoot during the first growing season. If germination occurs over a long period, large plants may dominate smaller or later germinating seedlings, reducing uniformity. Top-pruning larger seedlings encourages more uniform growth and improves shoot/root ratios by releasing smaller seedlings from competition. Seedlings may also be top or side pruned in the nursery during the dormant season or in the packing shed after lifting to provide a more desirable size and shape for packing and planting.

Roots are pruned to increase seedling uniformity, stimulate fibrous root development, and improve root/shoot ratios. Fourwing saltbush grows rapidly and produces an extensive root system during the first growing season. Excessively large root systems are produced when seedling densities are inadequate or germination occurs over a long period of time. Severing the taproot of fourwing saltbush serves to stimulate growth of lateral roots that are stronger and less easily damaged during lifting. Pruning taproots of rapidly growing species one or more times during the growing season at increasing depths (for example: 4, 6, and 8 inches (10, 15, and 20 cm) also prevents the development of a thick taproot at the normal lifting depth. Damage of thick, unpruned taproots during lifting leaves an open wound that is easily infected. Lateral root pruning is used to increase fibrous root development, control seedling size, and facilitate lifting.

Most chenopods are spring lifted prior to breaking dormancy. The stems and branches of many seedlings are rigid, brittle, and easily broken during lifting and packing and cannot be stored compactly. Fourwing saltbush and winterfat seedlings have been refrigerated in Kraft paper bags with polyethylene liners at 32° to 34° F (0° to 1° C) at the Lucky Peak Nursery for periods of 1 to 2 months before being planted.

OUTPLANTING

In southern Idaho, bareroot chenopod seedlings have been used in species adaptation trials and planting projects to enhance forage production and cover quality on arid rangelands adjacent to agricultural lands. Two outplantings will be described: (1) a test designed to aid in the development of grading criteria for fourwing saltbush seedlings and (2) an intertransplanting in a crested wheatgrass stand. Both trials were conducted within the Bell Rapids Study Area on the Snake River Plain in Twin Falls County, Idaho (see Shaw, Sands, and Turnipseed, this proceedings).

Fourwing Saltbush Seedling Grading Study

Fourwing saltbush bareroot seedlings grown at the Lucky Peak Nursery from a Sanpete County, Utah, seed source were lifted as 1-0 stock on March 9, 1982. Seedlings were grown at a nursery bed density of 10 per square foot ($108/m^2$) and were not root or top pruned. Lifted seedlings were graded into one of three size classes or a cull category based on the criteria listed in table 3. Thirty seedlings of each size class were handplanted at the Bell Rapids site on April 12, 1982. For each size class, 10 seedlings were planted in a randomly selected row within each of three blocks. Seedlings were planted on 8-foot (2.4-m) centers. The planting site was clean cultivated prior to planting, but a heavy cover of Russian thistle (Salsola kali L.) and

Table 3.--Comparison of three size classes of fourwing saltbush bareroot transplants after one growing season at the Bell Rapids study site, April 12, 1982 planting.

	Culls	Size class I	Size class II	Size class III
Grading criteria				
Shoot length (cm)	<5	5-10	10-20	>20
Root length (cm)	<30	30-35	30-35	>35 Taproot frequently severed
Caliper (root crown [mm])	<5.0	<5.0	5.0-7.5	>7.5
Percent of seedlings lifted	8	36	38	18
Growth performance[1]				
Survival (percent)		[2]37[a]	67[b]	13[a]
Height (cm)		12[a]	15[a]	22[a]
Crown (cm)		9[a]	9[a]	19[b]

[1]Seedlings were evaluated on October 12, 1982.

[2]Means followed by the same letter within rows are not significantly different ($P \leq 0.05$).

cheatgrass brome (Bromus tectorum L.) developed during the spring and summer. Survival, maximum seedling height, and maximum crown diameter measurements for each seedling were determined on October 12, 1982 (table 3). Results were tested by a one-way analysis of variance and the Duncan multiple range test (Steele and Torrie 1960).

Results--After one growing season, survival of intermediate (size class II) seedlings was significantly greater than that of the other two classes. Seedlings of the three size classes did not differ significantly in height, but crown diameters of the large size class (III) were significantly greater than those of the other two classes.

Grading criteria have not been developed for chenopod seedlings. McKell and Van Epps (1981) found plants with top growth consisting of several stems to be preferable to those with a single stem. Fourwing seedlings used in the present study had one main stem, but all had formed lateral branches. Results of this limited trial indicate that size class I seedlings may have had inadequate root and shoot development to establish and compete with other vegetation. Size class III seedlings had thick taproots, most of which were severed by undercutting prior to lifting. Lateral root development of these seedlings was very limited and the extensive lateral branching of the shoots caused the seedlings to be bulky and difficult to handle and plant. Results of this trial indicate that good survival can be obtained using healthy stock of adequate size even under semiarid conditions and amid competition. However, additional work is needed to better define plant characteristics which contribute to outplanting success and to determine whether root and top pruning treatments might improve survival.

Mechanical Transplanting

Seedlings of nine accessions of six shrub and forb species were intertransplanted into an established stand of crested wheatgrass on March 22, 1978. Planting stock included dormant 1-0 bareroot transplants of Wyoming big sagebrush (Artemisia tridentata Nutt. ssp. wyomingensis Beetle & Young), winterfat, Munro globemallow (Sphaeralcea munroana [Dougl.] Spach), and four accessions of fourwing saltbush (table 4). Dormant container seedlings of Nevada ephedra (Ephedra nevadensis Wats.) and Anderson peachbrush (Prunus andersonii A. Gray) grown in Leach tubes and hardened overwinter were also planted. Planting was accomplished by hand feeding the seedlings through a Forestland tree transplanter at 3- to 10-foot (0.9 to 3.0 m) spacings. The transplanter effectively cleared the crested wheatgrass from a furrow approximately 30 inches (76 cm) wide and 6 to 8 inches (15 to 20 cm) deep. Survival and maximum height and crown measurements of each shrub were recorded annually in late summer in 1978 and 1982.

Results--Survival of all fourwing saltbush, winterfat, and Wyoming big sagebrush accessions ranged from 77 to 100 percent following five growing seasons (table 4). Nearly all shrubs which did not survive succumbed during the first year. Nevada ephedra and Anderson peachbrush are not native to the area. Survival of these species declined during the first three growing seasons, but leveled off during the fourth year. Plants of both species have developed very slowly. Nevada ephedra is easily propagated in the nursery or greenhouse, but root and shoot systems of the seedlings are fragile and easily damaged during lifting or planting. Although survival of Munro globemallow has declined steadily, plants began flowering during the first growing season and the accession has spread from seed.

The furrow formed by the tree transplanter effectively released the shrubs from competition during the first two growing seasons. It did not become infested with weeds, but has slowly been reinvaded by crested wheatgrass. Van Epps and McKell (1983) obtained significantly higher survival for bareroot stock by controlling competition for 2 years.

Table 4.--Survival and growth of mechanically transplanted seedlings of nine accessions of six shrub and forb species after one and five growing seasons at the Bell Rapids Diagonal Tract, March 1978 planting.

Species	Source	Number planted	Year of evaluation	Survival	Height	Crown
				Percent	Mean (standard deviation)	
					--------cm--------	
Artemisia tridentata wyomingensis	Carey, Blaine Co., Idaho	150	1978	96	31(11)	14(5)
			1982	93	85(16)	73(22)
Atriplex canescens	Reynolds Creek, Owyhee Co., Idaho	103	1978	100	31(18)	74(17)
			1982	100	25(15)	116(41)
Atriplex canescens	Bliss, Gooding Co., Idaho	8	1978	100	33(19)	22(10)
			1982	100	72(15)	129(26)
Atriplex canescens	Nevada	81	1978	78	32(16)	20(11)
			1982	77	100(20)	161(48)
Atriplex canescens	New Mexico	108	1978	93	27(14)	18(10)
			1982	86	72(19)	123(46)
Ceratoides lanata	Hatch, Garfield Co., Utah	103	1978	97	24(13)	13(7)
			1982	93	67(15)	58(26)
Ephedra nevadensis	Wah Wah Valley, Beaver Co., Utah	107	1978	94	11(4)	11(4)
			1982	38	33(19)	21(13)
Prunus andersonii	Story Co., Nevada	52	1978	52	18(6)	10(4)
			1982	37	21(13)	13(9)
Sphaeralcea munroana	Boise, Ada Co., Idaho	101	1978	98	16(9)	19(11)
			1982	66	41(14)	53(27)

CONCLUSIONS

Nursery production records and outplanting trials indicate that seedlings of several chenopod species can be produced in a bareroot nursery and established on wildland sites. Seedlings may be used to stabilize disturbed areas and provide rapidly developing forage for livestock and big game and cover for birds and other small animals.

Chenopod seedlings in the nursery bed frequently vary in size and density as a result of typically low seed fill and erratic germination. Fourwing saltbush grows rapidly, producing a thick taproot and a densely branched shoot system. Pruning may be necessary to control plant size, improve shoot/root ratios, and facilitate handling. Shadscale and Gardner saltbush are slower growing and may be lifted as 1-0 or 2-0 stock depending upon growing conditions and seed source. The shoot systems of most seedlings tend to become woody, rigid, and sometimes brittle. This characteristic and the branching habits of fourwing and Gardner saltbush complicate handling, packing, and planting.

Results of an initial seedling grading trial indicate that best survival of fourwing saltbush transplants may be achieved using seedlings of an intermediate size class. Seedlings with shoots 4 to 8 inches (10 to 20 cm) in length and root systems which were not damaged during lifting demonstrated an ability to quickly become established and grow in dry areas.

Mechanical transplanting is a rapid means of planting large numbers of seedlings during short periods of favorable soil moisture. This technique may be used to remove competing grasses and transplant shrub seedlings within established crested wheatgrass stands. Reinvasion of crested wheatgrass into the furrow created by the transplanter occurred slowly and the incidence of annual weeds was minimal. Addition of shrubs to crested wheatgrass stands increases forage production and extends the period of grazing. Clusters of shrubs may be established by this technique to provide cover for upland game birds and other animals.

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PROPAGATION OF FOURWING SALTBUSH (*ATRIPLEX CANESCENS* [PURSH] NUTT.)

BY STEM CUTTINGS

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ABSTRACT: A technique that describes rooting of fourwing saltbush (*Atriplex canescens* [Pursh] Nutt.) stems is given. In general, nonterminal vegetative branches work best. Rooted cuttings can be produced under favorable circumstances as quickly as 10-14 days. Male plants, for some accessions at least, root better and more quickly than female plants.

INTRODUCTION

Rooted cuttings of fourwing saltbush (*Atriplex canescens* [Pursh] Nutt.) are needed to establish seed orchards and other plantations where the gender and position of plants are important. Fourwing saltbush is subdioecious with at least three genders (McArthur and Freeman 1982). Moreover, rooted cuttings can be used to propagate superior individual plants for a variety of purposes including breeding programs and provision of superior or uniform outplanting stock (Everett and others 1978; McArthur and others 1978; Richardson and others 1979).

Atriplex canescens is an attractive candidate for propagation by vegetative cuttings because some of its populations (Woodmansee and Potter 1970; Stutz and others 1975) and related species (Nord and others 1969) are known to reproduce by vegetative means. In fact, several researchers have successfully rooted stems of fourwing saltbush and other *Atriplex* species (Nord and Goodin 1970; Wieland and others 1971; Ellern 1972; Wiesner and Johnson 1977; Everett and others 1978; Richardson and others 1979). However, the previously described methods were generally performed on small sample sizes, on few populations, were not specifically designed for fourwing saltbush, or required several weeks for successful rooting. In the course of our studies we found we could have high success in a short (2-week) period. This paper reports our technique.

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MATERIALS AND METHODS

Stem sections of current and prior years' growth were taken from several naturally occurring populations (table 1) and from plantations of 'Rincon' fourwing saltbush[1] (table 2). If it was necessary to store plant material before processing, the branches were stored in an ice chest or coldroom. Cuttings were taken year round. Our cutting technique is more similar to that of Richardson and others (1979) than other published techniques.

Table 1.--Rooting of cuttings from natural populations of fourwing saltbush.

Population	Chromosome number	Gender	Number of plants	Number of plants with 50% > rooted cuttings
Little Sahara Sand Dunes, Juab Co., Utah	2x	female	11	11
		male	11	11
Kingston Canyon, Paiute Co., Utah	4x	female	17	14
		male	11	10
		monoecious	12	10
Rincon Blanco, Rio Arriba Co., New Mexico	4x	female	3	3
		male	3	3
		monoecious	3	3
Spanish Fork, Utah Co., Utah	4x	female	12	11
		male	11	11
		monoecious	10	9
Grantsville, Tooele Co., Utah	6x	female	8	6
		male	11	11
		monoecious	7	4
TOTALS			130	117

[1]McArthur, E. D.; Stranathan, S. E.; Noller, G. L. 'Rincon' fourwing saltbush--proven for better forage and reclamation. Unpublished article in press at Rangelands.

Table 2.--Rooting of 'Rincon' fourwing saltbush cuttings.

Year[1]	Gender	Number of plants	Number of ramets	Success: Number of plants > 50 percent	Success: $\overline{x}$, Percent of all ramets
1978	female	22	1,592	8	38.1
	male	25	1,656	8	37.0
	monoecious	33	1,893	1	16.2
	all	80	5,141	19	29.6
1979	female	22	3,156	12	76.6
	male	10	620	10	84.2
	monoecious	4	256	4	89.8
	all	36	4,032	16	78.5
1982	female	6	1,084	NA	42.7
	male	4	465	NA	68.2
	all	10	1,549		50.8

[1]The 1978 work was accomplished at the Snow Field Station, Ephraim, Utah; the 1979 work at the Shrub Sciences Laboratory, Provo, Utah; and the 1982 work at the Upper Colorado Environmental Plant Center, Meeker, Colorado. Mechanical failures of misting and air conditioning systems lowered the success for 1978 and 1982.

To make the cuttings, the tops of the stem sections, including the upper leaves with the stems, were cut straight across with a sharp razor blade. The bottom of the stem section was cut sharply at a 45° angle. The lower inch and a half (3.8 cm) of the stem was stripped of leaves and branches. Large drooping, upper leaves were also removed. This was done in an attempt to reduce wilting and to avoid leaf contact with the planting media (peat pellets). Cuttings that had two or three upper nodes with leaves, branches, or both, remaining after the lower ones were removed were generally selected for rooting. Long stems produced several cuttings.

After this initial preparation, the cuttings were placed in a 20-20-20 (nitrogen-phosphate-potash) fertilizer solution (30 g/gal or 7.9 g/liter) for at least 1 hour. As the cuttings were removed from the solution, they were dipped in "Rootone F" rooting hormone powder, and inserted into moisted "Jiffy-7 (703)" peat pellets. W. R. Oaks[2] reports success with concentrated growth regulators and no fertilizer soak.

The cuttings were then placed on a mist bench either on plastic trays with drain holes or on beds of perlite. In the summer (May-October) the misting regime was one or two 30-second bursts every half hour from 6 a.m. to 5 p.m. From 5 p.m. to 6 a.m. the 30-second bursts were given every 45 minutes. Our system had a 10-minute mist-activator clock which was controlled in turn by a 24-hour clock by 15-minute intervals. From November to April the misting system was considerably drier--7 to 15 seconds each hour and a half. Mist room temperature was maintained at 60° to 70° F (16° to 21° C).

[2]Oaks, W. R. Personal communication with authors, 1983.

After roots were visible outside the peat pellets, the cuttings were placed in a pre-dampened potting medium in 4- by 4- by 4-inch pots (10.2- by 10.2- by 10.2-cm). The potting medium consisted of five parts peat, three parts vermiculite, and two parts sand with amendments (table 3). The plants were then grown to size and maintained in greenhouses or lathhouses, depending upon season.

Table 3.--Fertilizer amendments added to 3.4-ft^3 (0.9-m^3) potting medium.

Amendment	Quantity
	grams
Dolomitic limestone	555
Agricultural limestone	75
Calcium nitrate	81
Phosphate	63
Osmocote	108
FTE[1]	9
Sesquestrene-138	3
Gypsum	252

[1]Frittered trace elements (manganese, iron, copper, zinc, boron, molybdenum).

RESULTS AND DISCUSSION

We found, as did Richardson and others (1979), that fourwing saltbush cuttings could be rooted best in the summer. Our success was over 90 percent for some plants during July. The 10,000 cuttings reported in table 2 are a fraction of the number of cuttings we have produced. The results for 1979 (table 2), which were from

cuttings all collected in July or August, illustrate the high success rates attainable using our methods. Plants root much more rapidly in the summer. In central Utah, cuttings made in July and August would routinely be ready for transplanting in 3 weeks. In January, 6 weeks were required to develop roots.

In general, succulent current year's growth beginning at the annual growth scar proved to root most readily. We recommend that one to three segments 2.5 to 5 inches (6.4 to 12.7 cm) long from current year's vegetative branches be used. Freshly cut branches are best, but we have had success with branches stored at about 35° F (2° C) up to 5 days. We have also had success with woody branches and floral branches. Nevertheless we recommend nonterminal portions of current year vegetative branches. Some natural populations (table 1) did not have a sufficient number of the "ideal" succulent vegetative branches for propagation and the "nonideal" branches did produce some roots. The method has been demonstrated successfully on several morphological forms, chromosome races, and genders (table 1). Individual plants in populations have been reported to vary in the amount of roots they will produce (Everett and others 1978; Richardson and others 1979). Our experience has been that some roots are produced by almost any plant, but some populations and plants root much more profusely than others (table 1).

Our results, taken in total (tables 1 and 2), do not prove different rooting responses of the genders. Richardson and others (1979) drew this conclusion. However, the 1982 sample does have a highly significantly (DF=1; $X^2=84.3$, $p \ll 0.01$) different rooting response between male and female cuttings. McArthur[3] has data that show that rooted male cuttings have much more rapid early growth than do monoecious and female cuttings. Results of our present experiments (fig. 1) show that male 'Rincon' fourwing saltbush cuttings root more rapidly than females.

ACKNOWLEDGMENTS

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[3]McArthur, E. D. Provo, UT: Data on file at Shrub Sciences Laboratory; 1983.

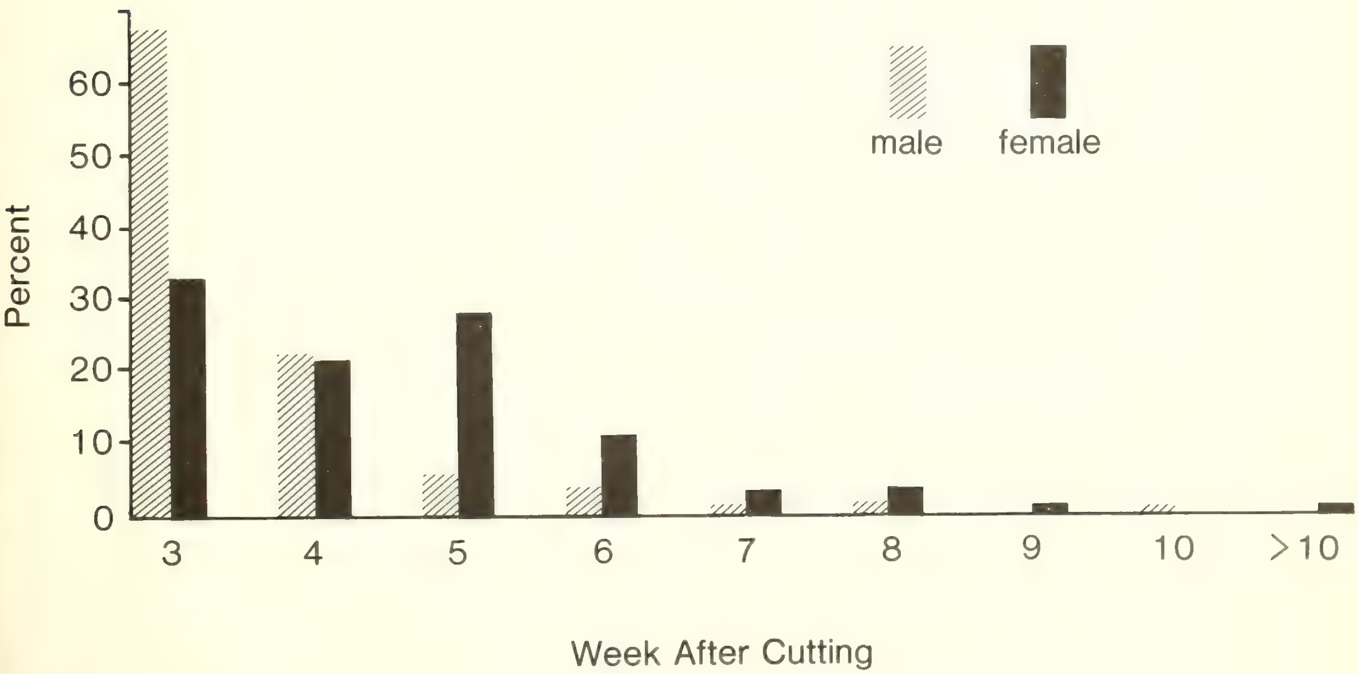

Figure 1.--Week after cutting that roots appeared by gender. Data collected in 1982 at Upper Colorado Plant Materials Center on cuttings made during the first week of August.

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METHODS FOR ESTABLISHING FOURWING SALTBUSH (Atriplex canescens [Pursh]Nutt.) ON DISTURBED SITES IN THE SOUTHWEST

Earl F. Aldon

ABSTRACT: This paper outlines: (1) the techniques for establishing fourwing saltbush (Atriplex canescens [Pursh]Nutt.) on disturbed sites using transplants, (2) methods needed for establishing this plant on surface coal mine areas by direct seeding and with supplemental irrigation, and (3) the long-term survival of fourwing saltbush on reclaimed coal mine spoils.

INTRODUCTION

Fourwing saltbush (Atriplex canescens [Pursh] Nutt.), an excellent soil stablizer, is a nutritious all-season forage plant for grazing animals; it provides food and cover for wildlife and traps sediment on alluvial flood plains. A 20-year watershed rehabilitation project has concentrated research on the establishment of this plant on disturbed areas in the Southwest (Aldon 1973). In the course of these studies, the requirements for growing seedlings and successfully transplanting these plants on disturbed sites have been worked out and are listed in this paper.

In addition, research has been conducted on methods for direct seeding of fourwing saltbush on areas disturbed by the surface mining of coal in the Southwest (Aldon 1975). Fourwing transplants have also been used, with and without supplemental irrigation, to establish these shrubs on raw mine spoil. These findings as well as the long-term survival of these plantings are included here.

LITERATURE REVIEW

Many workers have tested methods for growing this desirable plant under field conditions. Cassady and Glendening (1940), working in the Southwest, thought transplanting fourwing saltbush seedlings during the rainy season was best. Plummer and others (1966) reported seedlings, nursery stock, or wildlings could be transplanted easily early in the spring. Burnham and Johnson (1950), however, reported results of their attempts to transplant seedlings to the field in northeastern New Mexico were poor.

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Springfield (1970) found the growth of transplants in New Mexico differed according to source of seed and thought seed should be obtained from nearby or north of the planting site. Aldon (1976) found similar results in New Mexico. Springfield (1970) tried 1-year-old bare-root stock grown at the Soil Conservation Service (SCS) Los Lunas Plant Materials Center and found survival best when soil moisture was near field capacity, temperatures were cool at the time of planting, and grass competition was eliminated. Plummer and others (1966) found 16- to 20-week-old container grown seedlings were especially successful in field plantings in Utah. Springfield (1970) found survival of transplants exceeded 50 percent after 3 years at all sites if seedlings were at least 8 weeks old and 6 inches (15.2 cm) high. Direct seeding has also been tried. Hervey (1955) reported spring seedings were more successful than fall seedings in Colorado. Plummer and others (1966) obtained the best stands from winter planting; seeds were broadcast on snow and covered by chaining in late winter or early spring. Springfield (1970) thought seedbed preparation probably was necessary to obtain good stands of fourwing saltbush by direct seeding. Plowing was the best method of seedbed preparation where the native cover was composed mainly of undesirable plants. Spring and midsummer seedings were more successful than fall seedings in the Southwest. Success of seeding depended largely on the amount and seasonal distribution of precipitation during the period when temperatures were favorable for germination and establishment. Control of rabbits and rodents, where they are numerous, was recommended.

GROWING TRANSPLANTS (Aldon 1970a)

1. Collect seeds from plants growing near the site where planting is contemplated. Gather seeds in late October or early November, after they are mature and dry, but before they fall. Seeds are a light brown color at this time. SCS cultivars may also be used if they have wide adaptability.

2. Store over winter in open plastic bags in a dry place at room temperature. Special storage conditions are not necessary (Springfield 1968). Refrigeration does not improve seed viability.

3. In early April, remove wings from

seeds and select 100 seeds at random. Cut them in half and count the filled and hollow seeds. Filled seeds usually are viable (capable of germinating). Compute the number of seeds needed so that about four will germinate in each planting container.

4. Mix thoroughly two-thirds good garden soil with one-third soil taken from under a fourwing saltbush plant and place in 2- by 2-inch (51- by 51-cm) wide and 3-inch (76-cm) deep heavy-weight felt paper plant bands.

Line bottom of flats with heavy plastic. These containers pack tightly and hold up well in field transplanting. This soil mix is necessary to inoculate the plant with growth-stimulating micro-organisms.

5. Place enough seeds on the surface to produce about four seedlings and cover with one-fourth inch (7 mm) of the soil mix. Planting should start sometime between mid-April and mid-May when outdoor temperatures are optimum, between 55° and 75° F (12°-22° C). Seeds began germinating within 3 days at 65° to 73° F (19°-21° C).

6. Water daily with a fine mist to keep the surface moist. Heavy watering will float seeds out of the soil. Keep the bands where the sun will hit them for several hours a day. When plants are one-half inch (14 mm) tall, they can be flooded from the top when needed.

7. When plants are about 3 weeks old, thin to one per band. Remove grasses and weeds from the bands as they appear.

FIELD PLANTING (Aldon 1970b)

1. Plant in areas that will be flooded periodically but not inundated more than 30 hours. In the Southwest, it is important to wait until the probability for sizable (>0.40 inch; >10 mm) summer thunderstorms exceeds 50 percent, generally in late July or early August. Soil moisture stress should be less than 2 atmospheres of tension (Aldon 1972). For alluvial bottomlands, this is about 13 percent soil moisture.

2. Seedlings should be planted before 10 a.m. to minimize stresses. Plants should be shaded or covered and watered well while being transported to the planting site.

3. Make a 4-inch (11-cm) deep hole, insert plant band, and damp soil around it. The band top should be at ground level, not below. Roots apparently need not be laid straight down. They can be bent, but should not be broken.

4. Plant with 5-foot (1.5-m) spacings. It is unreasonable to expect greater plant densities through revegetation than would be found on undisturbed sites. In favorable years, plants can grow 2 feet (62 cm) tall the first year.

5. Cover transplanted seedlings with straw to minimize stresses and reduce frost heaving that may occur the first winter. Spray straw mulch and fourwing saltbush plants with 1:1 mixture of water and animal repellent.

SEEDLING PLANTING ON THE MCKINLEY COAL MINE

The McKinley, 20 miles northwest of Gallup, operates in the Gallup Mesaverde coal field. The climate is semiarid. Annual precipitation averages 10 to 14 inches (20.5-36 cm), a third of which falls as high-intensity rains in July and August. Another third falls as snow from December through March. Dry, windy weather prevails during the spring; less than 1.5 inch (38 mm) of precipitation falls from April to June. Elevation ranges from 6,800 to 7,300 feet (2,000-2,200 m). Temperatures reach extremes of -35° to 95° F (-38° to 35° C). Pinyon (*Pinus edulis* Engelm.)-juniper (*Juniperus monosperma* [Engelm.] Sarg.) is the dominant vegetation, occupying the plateaus, benches, mesas, rocky breaks, and steeper slopes. Associated with the trees are several shrubs, such as mountain-mahogany (*Cercocarpus montanus* Raf.) and cliffrose (*Cowania mexicana* D. Don), and a sparse herbaceous understory, including squirreltail (*Sitanion hystrix* [Nutt.] J.G. Sm.). The relatively narrow valleys filled with moderately deep alluvium support big sagebush (*Artemesia tridentata* Nutt.) with an understory mainly of western wheatgrass (*Agropyron smithii* Rydb.) and blue grama (*Bouteloua gracilis* [H.B.K.] Steud.).

In August 1973, 50 seedlings of fourwing saltbush were transplanted at the mine. All seedlings were grown in asphalt-impregnated, paper plant bands which were removed before transplanting. The seedlings were transplanted with soil intact, and were watered in. The transplants were 3-month-old stock. The plot was fenced initially to exclude livestock and game, but fence integrity, at least against rabbits and small rodents, was not maintained. No additional water was provided.

Initial survival was checked in November 1973, and in October or November of 1974, 1978, and 1979.

In November 1973, 80 percent were alive and by October 1979, 67 percent of the seedlings had survived. The fourwing saltbush plants are vigorous, averaging between 2 and 3 feet (62-90 cm) in height, and about 2 feet (62 cm) in diameter. The plants were spreading by seedlings. Progeny seedlings were vigorous and well-established (Aldon and Pase 1981). Precipitation was average over the period.

STUDIES AT THE NAVAJO MINE

The Navajo Mine is located near Farmington, N. Mex., in the Four Corners area of the United States.

The area surrounding the study area is rangeland with a scattering of low-growing shrubs. Principal grasses include galleta (Hilaria jamesii [Torr.] Benth.), alkali sacaton (Sporobolus airoides [Torr.] Torr.), and Indian ricegrass (Oryzopsis hymenoides [R. & S.] Ricker). Shadscale (Atriplex confertifolia [Torr. & Frem.] Wats.), fourwing saltbush, and broadscale (Atriplex obovata Moq.) are the most important shrub species. At higher elevations, pinyon and juniper trees are found scattered on mesa tops. Elevation ranges from 5,000 to 6,500 feet (1,524-2,000 m). Annual precipitation averages only 6 to 8 inches (15-20 cm). Summer is usually wetter than winter; spring and fall are the drier seasons. Temperature extremes range from -25° to 115° F (-32° to 44° C).

The plantings were on untreated spoil material (no topsoil used) from the Watson Pit area of the Navajo Mine. The spoil is a dark, shale-derived material having the following characteristics:

Sand, percent	31
Silt, percent	27
Clay, percent	42
Textural class	clay
Sodium absorption ration (SAR)	44
Electrical conductivity x 10^3	15
pH	7.7

Direct Seeding Trials

Fourwing saltbush was direct-seeded at the Navajo Mine on a low-lying area in March 1973. The area had a wet winter and early spring, so residual soil moisture was good; about two times normal precipitation had fallen. Seeds were planted when temperatures were optimum--62° F (16° C) daytime and cold nights. Seeds were hand broadcast over the area and covered by raking. No supplemental watering was done. In May, about 400 plants had germinated. By September 1973, over half of the plants had survived. Two years later, survival was 15 percent and plants averaged 32.4 inches (80 cm) in height and 29.8 inches (73 cm) in diameter. About 64 percent are male plants and 36 percent female plants (Aldon 1975).

Five years after establishment, 62 percent of the previously established plants were alive and averaged 2.3 feet (72.4 cm) in height and 1.8 feet (55.4 cm) in diameter. The plants were 14 percent shorter and 27 percent narrower than they had been 5 years earlier probably due to plant competition. No grazing was present during this time. After some mortality a plant now occupies about 30 ft^2 (2.9 m^2), whereas a mature plant occupied about 20 ft^2 (1.8 m^2) 2 years after planting. Precipitation was average over the period (Aldon 1981).

Drip Irrigation Tests

Drip irrigation is a method which allows water to drip slowly from small emitters along a pipe. Two 100-foot (30-m) lengths of 1/2-inch (13-mm) plastic pipe were laid about 20 feet (6 m) apart on graded spoil material at the Navajo mine. Emitters were located at 1-foot (0.3-m) intervals along 60 feet (18 m) of each line. Each line was connected to a water source. Three-month-old transplants of fourwing saltbush, grown by techniques outlined above, were planted alternately at each emitter. Ten transplants of each species, used as controls, were planted between the lines but not watered.

Seedlings were transplanted in mid-September 1973, and watered twice a week (eight times) until the first hard frost. Discharge rates under gravity feed were 1.4 gallons (5.3 liters) per emitter per hour. Each emitter delivered about 4 gallons (15 liters) per watering. Plants were not watered after the first growing season.

Drip irrigation significantly improved survival though planting was late in the season. Height, diameter, and size index (height diameter) were also significantly better. This benefit was still apparent 22 months after planting (Aldon 1975).

Long-term survival of fourwing saltbush on these irrigated plots was 88 percent. Average plant height went from 2 feet (62 cm) in 1975 to 2.8 feet (85.3 cm) in 1979; average plant diameter went from 1.9 to 3.2 feet (59.7 cm to 98.3 cm). Each plant now occupies about 23 ft^2 (2.23 m^2). Plant size and spacing seem to be related. Closely spaced plants were smaller and had large die-offs compared to plants that were more widely spaced initially (Aldon 1981).

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SEEDING TECHNIQUES TO IMPROVE ESTABLISHMENT OF FORAGE KOCHIA (KOCHIA PROSTRATA [L.] SCHRAD.) AND FOURWING SALTBUSH (ATRIPLEX CANESCENS [PURSH] NUTT.)

Richard Stevens and Gordon A. Van Epps

ABSTRACT: Seeding trials were conducted to determine the effects seeding techniques, mulching, and seed cleaning techniques have on seedling emergence. The largest number of forage kochia (Kochia prostrata [L.] Schrad.) seedlings occurred when seed was not covered at seeding time. Mulching did not increase the number of emerged seedlings. Mulching increased the number of fourwing saltbush (Atriplex canescens [Pursh] Nutt.) seedlings. Utricle size and the absence or presence of utricle wings did not affect seedling numbers. Significantly more fourwing saltbush seedlings emerged when utricles were covered at seeding.

INTRODUCTION

Forage kochia (Kochia prostrata [L.] Schrad.) is a low-growing (under 35 inches [89 cm] perennial chenopod shrub introduced to North America from southern Eurasia (Keller and Bleak 1974). This shrub shows promise of being an important forage producer and soil stabilizer on arid western ranges (Blauer and others 1976). Important characteristics exhibited by forage kochia in the Intermountain West are: fairly high salt tolerance (Francois 1976; McArthur and others 1978), drought tolerance (Larin 1956; Balyan 1972; Keller and Bleak 1974; McArthur and others 1974 and 1978; Moghaddam 1978; Aldon and Pase 1981; Romo and others 1984), adaptability to cold (-15°F [-26°C]) and hot (115°F [46°C]) climates (Blauer and others 1976; McArthur and others 1978; Aldon and Pase 1981), low oxalate levels (Britton and Sneva 1977; Williams 1977; Davis 1979), ability to spread rapidly from seed (McArthur and others 1974; Frischknecht and Ferguson 1979), rapid and high seed production (Balyan 1972; McArthur and others 1974), semi-evergreen habitat (Balyan 1972), good protein content throughout the year (Akhmetov 1970; Moghaddam 1976 and 1978; Otsyina and McKell 1984; Otsyina and others, this proceedings), good palatability to livestock and big game (Larin 1956; Balyan 1972; Blauer and others 1976; Nemati 1977; Otsyina and McKell 1984; Welch and Davis[1]), provision of food and cover to upland game birds (Stevens[2]), compatibility with other perennials (Stevens[2]), competitive with annuals (Stevens[2]), and some fire tolerance (Stevens[2]).

Establishment of forage kochia by direct seeding has been sporadic (Young and others 1981; Romo and Haferkamp 1984; Stevens[2]). Problems with retention of seed viability could have some effect on sporadic establishment (Waller and others 1979; Jorgensen and Davis, this proceedings). Reproduction from established stands has filled in interspaces. Natural spread has occurred in the direction of the prevailing winds at over 30 sites in Utah. Experience has demonstrated that the most productive results from direct seedings were obtained when seeds were not covered. Similar results were obtained with K. scoparia [L.] Schrad. (Everett and others 1983). An Agricultural Research Service report (USDA 1961) recommends that seed be drilled to 0.2 inches (0.5 cm) deep. Forage kochia has been established in Halogeton glomeratus C.A. Mey. in Ledeb. communities when seed was broadcast into the stands with no seed covering. Likewise, forage kochia has been established in cheatgrass brome (Bromus tectorum L.) stands by broadcast seeding on disturbed seedbeds (Stevens[2]).

Similarly, results have been sporadic with fourwing saltbush (Atriplex canescens [Pursh] Nutt.). Consistently good stands (350-450 plants/acre [140-180/ha]) have not been obtained in many rangeland seeding projects. A standard seeding procedure is to seed dewinged utricles 0.25 to 0.5 inch (0.6 cm to 1.2 cm) deep. Because of the importance and potential of fourwing saltbush in range improvement, this study also included that species to try to find ways of improving stand establishment. This study was implemented to determine the effects of various types of seed covering, dewinging, and mulching on seedling emergence.

METHODS

Seed trials were conducted at the Nephi Dryland Field Station near Nephi, central Utah. Soils are a clay loam. Annual precipitation during the study year (1980-81) was 14.7 inches (37 cm). The field had been summer fallowed for 2 years; the soil surface was slightly crusted with considerable cracking.

Richard Stevens is Wildlife Biologist, Utah Division of Wildlife Resources. Gordon A. Van Epps is Range Agronomist at the Utah State Agricultural Experiment Station; Ephraim, Utah.

[1]Welch, B. L.; Davis, J. N. In Vitro digestability of Kochia prostrata. Great Basin Naturalist, In press.

[2]Stevens, R. Data on file, Great Basin Experiment Station; Ephraim, Utah.

New seed of forage kochia grown at Snow Field Station, Ephraim, Utah, originating from Russia (P.I. 314929), and fresh fourwing saltbush seed collected east of Ephraim were used. Forage kochia seed was cleaned to over 95 percent purity (seed was considered clean with the bracts on). Fourwing saltbush utricles were divided into two size groups, large (when dewinged, utricle diameter greater than 0.125 inch [0.3 cm]) and small (less than 0.125 inch). One half of each size class was dewinged in a hammermill. One half of the dewinged seed was cleaned to 96 percent purity; the second half was not cleaned. Utricles with wings were cleaned to 99 percent purity. Mulch material consisted of cropped bitterbrush (Purshia tridentata [Pursh] DC.) limbs.

Site preparation and seeding occurred on January 27, 1981. Number of seedlings was counted the following spring and summer (May 29 and July 16). Plots were 4.9 feet (1.5 m) square. One thousand seeds were seeded into each plot. Treatments were replicated four times in a split plot design.

Seed treatments were: (a) forage kochia seed cleaned to 95 percent purity, and (b) fourwing saltbush seed with six different treatments: (1) large utricles with wings, (2) large utricles dewinged and cleaned, (3) large utricles dewinged and uncleaned, (4) small utricles with wings, (5) small utricles dewinged and cleaned, and (6) small utricles dewinged and uncleaned.

Soil treatments were: (1) broadcasting seed onto undisturbed soil, (2) disturbing the soil and broadcasting seed into it, (3) disturbing the soil, broadcasting the seed, followed by additional soil disturbance, and (4) broadcasting seed and then disturbing the soil. Soil disturbance consisted of dragging a garden rake with 1.33 inch (3.9 cm) tines through the plot twice.

Mulch treatments were: (1) cropped bitterbrush limbs, 1 inch (2.54 cm) deep, and (2) no mulch.

Seed of forage kochia were broadcast seeded into each soil treatment with and without a mulch covering. Seed from the six different fourwing saltbush treatments were broadcast seeded into each of the soil treatments, with and without a mulch covering.

Data were subjected to analysis of variance, and Newman-Kuels multiple range test (Woolfe 1968) to detect difference among the treatment means.

RESULTS AND DISCUSSION

Forage Kochia

Forage kochia germination occurred in early March, resulting in no significant difference in the number of seedlings between May 29 and July 16. The absence or presence of mulch did not significantly affect the number of seedlings. The plots (table 1) that were seeded and then disturbed (treatments 3 and 4) had the fewest number of seedlings. The largest number of seedlings occurred where seed was broadcast onto undisturbed soil (treatment 1). The most successful field and test plot plantings resulted when seed of forage kochia was intentionally or purposely scattered on the soil surface. The results of this study indicate that seed of forage kochia should not be covered after seeding.

Table 1.--Mean number of forage kochia seedlings in 1.5 m square plots resulting from four different seeding techniques.

Treatments	Mean number of seedlings per plot
1- Seed on soil surface	[1]16.4
2- Disturbed soil - seed	14.4
3- Disturbed soil - seed - disturbed soil	13.6
4- Seed - disturbed soil	9.1

[1]Values connected by the same line are not significantly different at the 1 percent level.

Fourwing Saltbush

Fourwing saltbush seed germinated later than forage kochia seed. There were significantly more seedlings on July 16 than on May 29 (table 2), indicating a considerable amount of germination occurrred in June and early July.

Fourwing saltbush seedlings are somewhat susceptible to frost (Plummer and others 1966). Mulching resulted in significantly more seedlings than were present on nonmulched plots (table 2). Mulch could

Table 2.--Mean number of fourwing saltbush seedlings in 1.5 m square plots on two dates and with various seeding techniques.

Item	Mean number of seedlings per plot
Treatment date	
May 29	0.3
July 16	1.0
Utricle size	
Small	[1]0.7
Large	0.5
Seed treatment	
With wings on	0.6
Dewinged - uncleaned	0.7
Dewinged - cleaned	0.6
Mulch	
No mulch	0.5
With mulch	0.8
Soil treatment	
Seed on soil surface	0.1
Disturbed soil - seed	0.4
Disturbed soil - seed - disturbed soil	1.0
Seed - disturbed soil	1.0

[1]Values connected by the same line are not significantly different at the 1 percent level.

protect seedlings from frost and other damaging climatic factors.

Utricle size did not have an effect on the number of seedlings that emerged; neither did dewinging or cleaning (table 2). Utricles are commonly dewinged for ease of handling and seeding; however, this treatment evidently does not reduce or enhance seedling emergence.

SUMMARY

Forage kochia, a potentially important shrub on western ranges, is an early spring germinator. The most successful seeding occurred when seed of forage kochia was broadcast seeded and not covered. Mulching did not enhance the number of seedlings.

Covering fourwing saltbush utricles resulted in the greatest number of seedlings. Mulching increased seedling numbers. There was no difference in the number of seedlings that emerged from winged and dewinged utricles. Utricle size did not affect the number of seedlings.

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DEVELOPMENT OF 'RINCON' FOURWING SALTBUSH, WINTERFAT, AND OTHER SHRUBS FROM SEED FOLLOWING FIRE

Warren P. Clary and Arthur R. Tiedemann

ABSTRACT: Seeding trials consisting of a shrub mix and a shrub-grass mix were established on a recent burn in central Utah. Shrubs included winterfat, 'Rincon' fourwing saltbush, Hobble Creek Vasey big sagebrush, and antelope bitterbrush. Shrub-grass mixes included, in addition to these species, 'Ephraim' crested wheatgrass, 'Paiute' drought-tolerant orchardgrass, Bozoisky Russian wildrye, and 'Magnar' basin wildrye. One-half of the plots were fertilized. Mean total shrub establishment ranged from 1,726 to 8,452 plants per acre (4 263 to 20 876/ha). Average winterfat and 'Rincon' fourwing saltbush establishment was 4,200 per acre (10 374/ha) and 1,400 per acre (3 458/ha). Fertilization significantly enhanced recruitment of big sagebrush. Shrub recruitment was reduced when grasses were seeded with shrubs, but was more strongly inhibited by residual native perennial grasses.

INTRODUCTION

Rehabilitation of rangelands by seeding began in the western United States in the late 1800's. More literature exists on range seeding than any other practice in range management (Heady 1975). As might be expected, there is a long history of impressive successes and disappointing failures.

Numerous factors affect seeding success and should be considered in seeding prescriptions (Plummer and others 1968). Matching the plant species to the climate and soil conditions is a major item. Although general agreement exists that species mixes are better than single species, little information is available on the performance of individual species in a mixture. The shrub, grass, and forb composition of a seed mix affects composition of the resultant plant community, but other factors, including competition, growth rate, drought tolerance, and climatic parameters, ultimately influence plant expression (Doerr and others 1983). Because of these variables, it may not be possible to predict the community that will result from a given mix of species.

Initial soil fertility may also be important, but apparently little or no work has been done in the Intermountain region on the possible benefits of starter fertilizer. Such fertilizers were essential for successful plant establishment in north-central Washington (Klock and others 1975). Nitrogen fertilizer applied to established plant stands has greatly increased production of crested wheatgrass (<u>Agropyron</u> <u>desertorum</u> Fisch.), but its effect on native vegetation has varied from modest to none (West and Skujins 1978). Recently, Doerr and others (1983) studied the effect of fertilization on biomass and cover of seeded shrubs, grasses, and forbs in a big sagebrush (<u>Artemisia tridentata</u> Nutt.)/western wheatgrass (<u>Agropyron</u> <u>smithii</u> Rydb.) area in Colorado. Fertilization significantly increased biomass of shrubs and grasses during the first season following seeding, but there was no significant response by seeded forbs. During the following 2 years, differences in biomass between fertilized and nonfertilized shrubs and grasses diminished to nonsignificance. Fertilization most benefited shrubs deprived of supplemental irrigation. Canopy cover was then two times greater on fertilized plots.

Lightning-caused wildfires in late July 1981 burned over 62,000 acres (25 100 ha) on the Oak Creek range study area in Millard and Juab Counties, central Utah. The Little Oak Creek fire burned across Forest Service, Bureau of Land Management, State, and private land--mostly in the big sagebrush (<u>Artemisia tridentata</u> Nutt.)/pinyon (<u>Pinus</u> <u>edulis</u> Engelm.)-juniper (<u>Juniperus</u> <u>scopulorum</u> Sarg.) zone. The fire was quite hot, resulting in several thousand hectares with virtually no debris and an exceptionally clean seedbed for attempts at revegetation. In December 1981, we established a study on this burn to compare revegetation success of several combinations of plant materials and a starter fertilizer.

The information in this paper is based on the first 2 years' observations from two seeding

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and fertilization treatments, and will focus on the performance of shrub species in relation to development of native and seeded grasses. One seeding treatment was a mixture of shrubs including the newly released 'Rincon' fourwing saltbush (McArthur and others 1982). The other was a mixture of grasses and shrubs including the newly released 'Paiute' drought-tolerant orchardgrass and 'Ephraim' rhizomatous crested wheatgrass varieties (Stevens and others 1983a and 1983b). The starter fertilizer treatment consisted of fertilization versus no fertilization.

METHODS

The study is near the center of the Little Oak Creek burn 30 miles (48 km) south of Nephi, Utah. The experiment utilized a randomized block design. Four blocks (study areas) were established to span an elevation gradient between 5,080 ft (1 540 m) and 5,520 ft (1 671 m) within the limits of the big sagebrush vegetation zone. The lowest area is near a greasewood (*Sarcobatus vermiculatus* [Hook.] Torr.) bottomland. The upper area is in the lower portion of a big sagebrush/pinyon-juniper ecotone. Within each block, 11 treatments were applied.

Four of these treatments were evaluated for this paper; a shrub seed mixture and shrub-grass seed mixture, each applied under fertilized and unfertilized conditions. The shrub materials were 'Rincon' fourwing saltbush (*Atriplex canescens* [Pursh] Nutt.), Hobble Creek[1] Vasey big sagebrush (*Artemisia tridentata* Nutt. var. *vaseyana*), winterfat (*Ceratoides lanata* [Pursh] Moq.), and antelope bitterbrush (*Purshia tridentata* [Pursh] DC). The shrub-grass mixture included the mentioned shrubs and the grasses Bozoisky[2] Russian wildrye (*Elymus junceus* Fisch.), 'Paiute' drought-tolerant orchardgrass (*Dactylis glomerata* L.), 'Ephraim' rhizomatous crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.), and 'Magnar' basin wildrye (*Elymus cinereus* Scribn. & Merr.).

The blocks were seeded in early December 1981. The 33- by 33-ft (10- by 10-m) plots were prepared by pulling a straight-tooth harrow behind a small tractor. Consumption of vegetation and litter by fire was complete and no additional seedbed preparation was considered necessary. Seed and fertilizer were broadcast and covered by dragging a light chain across each plot. All seed mixes were applied at the rate of 40 pure live seed (PLS) per ft^2 ($430/m^2$). On the shrub-only plots, each of the four species was planted at the rate of 10 PLS per ft^2 ($108/m^2$). In the shrub-grass plots, each of the eight species was applied at the rate of 5 seeds per ft^2 ($54/m^2$). Fertilizer was applied as 16-20-0-8, nitrogen (N), phosphorus (P), potassium (K), sulfur (S) to provide nitrogen at the rate of 50 lb per acre (56 kg/ha). On the fertilized plots on study areas 3 and 4, our treatments (especially the shrub-only treatment) were confounded by accidental aerial application of seed during the post-fire revegetation effort (table 1).

Sampling of the vegetation was conducted in April and August 1983. The total number of shrubs was counted at both times within each treatment. Only height measurements were made in April. Shrub height and average crown diameter measurements were made in August on the first 20 individuals encountered per species per treatment. Shrub height and crown diameter were used to

Table 1.--Species and rates seeded aerially during post-fire revegetation efforts.

Species	Rate	
	lb/acre	kg/ha
'Fairway' crested wheatgrass (*Agropyron cristatum* [L.] Gaertn.)	3.0	3.4
Intermediate wheatgrass (*Agropyron intermedium* [Host] Beauv.)	1.5	1.7
'Luna' pubescent wheatgrass (*A. intermedium* var. *trichophorum* [Link] Halacsy)	1.0	1.1
Russian wildrye	1.5	1.7
'Ladak' alfalfa (*Medicago sativa* L.)	1.5	1.7
Small burnet (*Sanguisorba minor* Scop.)	1.0	1.1
Yellow sweetclover (*Melilotus officinalis* [L.] Pallas)	.25	.28
'Manchar' smooth brome (*Bromus inermis* Leyss.)	.25	.28

[1] Hobble Creek is not a varietal release name. It refers to the area of origin of the seed near Springville, Utah.

[2] Bozoisky is not a varietal release name; it refers to the area of origin in Russia.

develop shrub volume estimates. Perennial herbaceous plant cover was sampled within each treatment in three randomly located 0.3- by 6-m belt transects. Cover, expressed as a percentage of soil surface covered by projection of foliar material onto the ground, was recorded for each seeded and native plant species present, within 20 contiguous plots in each belt transect. Seeded plant densities on the contiguous plots were also recorded. Where differences among treatments were significant according to the F-test, the Tukey procedure was used for mean comparisons (Steel and Torrie 1960).

In August, only study areas 2, 3, and 4 were measured. Study area 1 had such a heavy growth of annual plants that evaluation of seeded species was not feasible (fig. 1).

RESULTS AND DISCUSSION

Immediately after the fire, conditions for plant establishment appeared to be similar across the burned area. However, after the first growing season, major differences were apparent (fig. 1). Seedlings in study area 1 (near a greasewood bottom) were subjected to intense competition by annual plants such as bur buttercup (Ranunculus testiculatus Crantz), tumblemustard (Sisymbrium altissimum L.), pepperweed (Lepidium perfoliatum L.), cheatgrass brome (Bromus tectorum L.), Russian thistle (Salsola

Area 1

Area 2

Area 3

Area 4

Figure 1.--Views of study areas, August 1983.

iberica Sennen & Pau), and halogeton (Halogeton glomeratus C.A. Mey.). Study area 2 was subjected to periodic severe wind erosion for approximately 1 year after seeding. This resulted in the loss of 2 to 3 inches (5 to 8 cm) of topsoil, as measured from stumps of big sagebrush plants which had been burned to ground level. Nearly all the introduced and native seed was likely blown away. The surface of area 2 remained largely devoid of plant growth 2 years after the fire. Study areas 3 and 4 contained substantial residual native bunchgrasses--principally bluebunch wheatgrass (Agropyron spicatum [Pursh] Scribn. & Sm.) and were inadvertently seeded during post-fire revegetation efforts on the remainder of the burn (table 1).

Winterfat was the most successful shrub in terms of number of plants established (table 2). The recruitment of winterfat seedlings in April was nearly 1 percent of the number of seed planted. This significantly exceeded the success of the other three shrubs. Hobble Creek big sagebrush and 'Rincon' fourwing saltbush recruitment were 0.38 percent and 0.24 percent, respectively. Antelope bitterbrush with only a 0.04 percent recruitment, was far less successful than the other shrubs. The pattern of recruitment in August was similar to April with one exception: density of antelope bitterbrush seedlings had increased. Differences were not significant among the sagebrush, fourwing saltbush, and bitterbrush recruitments.

Table 2.--Average recruitment of shrub seedlings by species as a percent of planted seed.

	April[1]	August[2]
Winterfat	[3]0.82[a]	0.75[a]
Hobble Creek Vasey big sagebrush	.38[b]	.32[b]
'Rincon' fourwing saltbush	.24[b]	.18[b]
Antelope bitterbrush	.04[c]	.12[b]

[1]Data from study areas 1-4.

[2]Data from study areas 2, 3, and 4.

[3]Values in the same column followed by different letters are significantly different at $P < 0.05$.

The change in apparent recruitment between April and August was tested by comparing plant counts in study areas 2, 3, and 4. Area 1 was excluded from the April evaluation because values would have distorted the apparent change in recruitment and invalidate the comparison with August.

There was no significant change in mean recruitment from April to August for fourwing saltbush, significant decreases for winterfat and big sagebrush, but a significant increase for antelope bitterbrush (table 3). Antelope bitterbrush may have delayed seed germination or may develop more slowly to a 'findable' size than the other shrub species.

Fertilization significantly enhanced recruitment of big sagebrush on the shrub-only plots but had no effect on the other shrub species. Big sagebrush recruitment was doubled by fertilization on the April sample date and more than doubled by August. This result indicates that fertilization should be considered as a means of improving plant recruitment when seeding big sagebrush.

Shrub recruitment was not improved by fertilization on the shrub-grass plots.

Competition from perennial grasses tended to reduce recruitment of all four shrub species but big sagebrush was the only individual species for which the differences were statistically significant. On the shrub-grass/ fertilized treatment, big sagebrush recruitment was reduced by eight and 15 times for April and August, respectively, compared to the shrub/fertilized treatment.

Considerable grass competition was present even in plots where only shrub establishment had been intended. As a result of the inadvertent aerial seeding on areas 3 and 4, there was over 2 percent cover of seeded perennial grasses on shrub-only plots (table 4). Residual native perennial grasses on these plots provided approximately the same cover. Our seeding treatment more than doubled cover of seeded perennial grasses. Surprisingly, cover of native perennial grasses was nearly twice as great on shrub-grass as shrub-only plots. Apparently, the random shrub-grass plots within study areas 3 and 4 coincided with areas of greatest residual perennial grass cover.

Initially we expected that seeded grass species would present the most severe competition or resistance to establishment of seedling shrubs because the grass varieties had been selected for their ability to develop rapidly and for their hardiness under arid or semi-arid conditions. There was a great deal of variability in shrub recruitment between study areas 3 and 4, apparently unrelated to establishment of seeded grass species. Also, very few annual plants were present on areas 2, 3, or 4, so this was not a factor.

Table 3.--Comparative shrub recruitment in April and August on study sites 2, 3, and 4 expressed as percent of PLS applied.

Treatment	Fourwing saltbush		Winterfat		Big sagebrush		Antelope bitterbrush	
	April	August	April	August	April	August	April	August
Shrub/fertilized	[1]0.22[a]	0.31[a]	1.25[a]	1.00[a]	0.85[a]	0.76[a]	0.04[a]	0.08[a]
Shrub/not fertilized	.22[a]	.27[a]	1.02[a]	.90[a]	.43[b]	.33[b]	.08[a]	.22[a]
Shrub-grass/fertilized	.10[a]	.07[a]	.79[a]	.55[a]	.11[b]	.05[b]	.01[a]	.06[a]
Shrub-grass/not fertilized	.02[a]	.05[a]	.73[a]	.58[a]	.17[b]	.13[b]	.06[a]	.11[a]
MEAN	[2].14[A]	.18[A]	.95[A]	.76[B]	.39[A]	.32[B]	.05[A]	.12[B]
	NS		*		*		*	

[1] Values followed by the same lower case letter are not significantly different from other values in the same column at $P < 0.05$.

[2] Values followed by the same upper case letter are not significantly different between April and August for individual species at $P < 0.05$.

Table 4.--Percent cover of perennial herbaceous plants in study areas 2, 3, and 4.

	Shrub fertilized	Shrub not fertilized	Shrub-grass fertilized	Shrub-grass not fertilized
Seeded perennial grasses	2.28	2.25	5.83	4.33
Native perennial grasses	2.50	1.98	4.37	3.32
Perennial forbs	.65	1.22	.37	1.78
Total	5.43	5.45	10.57	9.43

Recruitment variability was, however, related primarily to the cover of native perennial bunchgrasses (fig. 2). These bunchgrasses, predominantly bluebunch wheatgrass, are not generally considered to be extremely competitive plants. However, they were well established in study areas 3 and 4 at the time of the fire and provided strong competition to emerging shrub seedlings early in the first growing season at a time when the seeded grasses were also just emerging. Seeded grasses may prove to be more competitive to shrubs in later years, but the natives surviving the fire appear to be the most effective competitors during initial seedling establishment. Our results were comparable to those of Blaisdell (1949). He found that good stands of perennial grasses often prevented establishment of sagebrush seedlings.

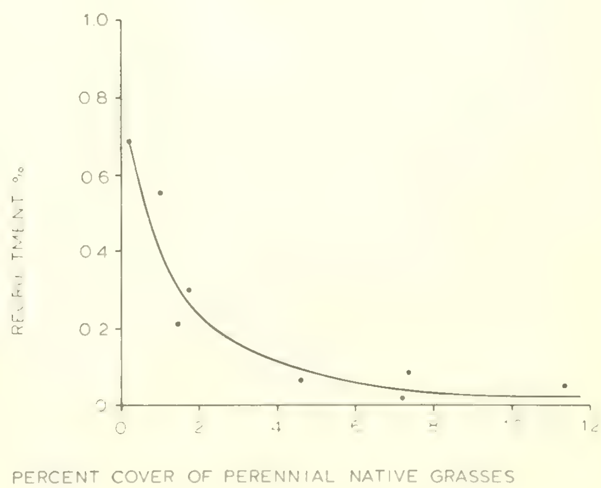

Figure 2.--Relationship of shrub recruitment to cover of native perennial grasses on study areas 3 and 4.

A native bunchgrass cover of only 1 percent in area 4 (as compared to 8 percent in area 3), few annuals, and no noticeable soil loss resulted in the best shrub recruitment (table 5). Land managers should carefully scrutinize the potential success of shrub establishment relative to the costs of seeding shrubs after fire in areas with adequate stands of perennial grasses.

Table 5.--Average shrub seedling recruitment on the four study areas in decreasing order.

Area	Elevation	April	August
	ft	---percent---	
Area 4 Juniper-sagebrush ecotone	5,520	[1]0.94[a]	0.88[a]
Area 1 Lower sagebrush zone	5,080	.33[b]	--
Area 3 Upper sagebrush zone	5,500	.18[bc]	.10[b]
Area 2 Mid sagebrush zone	5,280	.02[c]	.05[b]

[1]Areas followed by different letters are significantly different at $P < 0.05$ within the same month.

Although 'adequate' is a qualitative term that needs clarification in terms of density and cover, it is a relationship that needs to be developed if we are to make sound prescriptions for revegetating areas in the future.

The actual densities of shrub seedlings illustrate the greater success of shrub seedling establishment where fewer grasses were present. The shrub-only plots had about four times the shrub seedlings as the shrub-grass plots even though the seeding rate was only twice as heavy (table 6). In addition, net seedling reduction was considerably greater through the second growing season in the shrub-grass plots.

No guidelines exist delineating the number of shrubs needed to constitute a successful seeding. For a large stature shrub such as 'Rincon' with a crown spread of approximately 6 ft (1.2 m), 500 plants per acre (1 235/ha) would provide 32 percent canopy coverage or one-third of the site occupied. We suggest this would represent an acceptable level of establishment. This was achieved with shrub-only treatments but not with the shrub-grass. For smaller statured plants such as winterfat with a crown spread of about 18 inches (0.5 m), 32 percent cover would require approximately 7,800 plants per acre (19 260/ha). This level was not achieved with any treatment.

'Rincon' fourwing saltbush seedlings were significantly taller and produced the greatest crown volume per plot (number X height X width^2) of any shrub species (table 7). The average 'Rincon' fourwing

Table 6.--Densities per acre of shrub seedlings.

Species	Shrub mix		Shrub-grass mix	
	April[1]	August[2]	April	August
Winterfat	4,244	4,080	1,456	1,220
Hobble Creek big sagebrush	2,580	2,347	344	200
'Rincon' fourwing saltbush	1,436	1,260	340	133
Antelope bitterbrush	192	660	60	173
Total	8,452	8,347	2,200	1,726
Percent mortality	1		22	

[1] Areas 1-4.

[2] Areas 2-4.

saltbush at the end of the second growing season produced 20 times the crown volume of the average winterfat, and about 40 times the crown volume of Hobble Creek big sagebrush. Study area number 2 with a few very large 'Rincon' plants had five times the shrub crown volume of area 4, and 16 times the volume of area 3. These areas supported more small winterfat and sagebrush plants.

Table 7.--Height and crown volume of the shrub seedlings.

Species	Height	Volume
	inches	ft^3
'Rincon' fourwing saltbush	[1]10.9[a]	2.0[a]
Winterfat	6.9[b]	.7[b]
Antelope bitterbrush	5.6[b]	.1[b]
Hobble Creek big sagebrush	3.0[b]	.1[b]

[1]Species followed by different letters are significantly different at $P < 0.05$.

SUMMARY AND CONCLUSIONS

Four study areas were utilized in a seeding and fertilizer study on a large wildfire burn which occurred in July 1981. The treatments were applied in December 1981. All four study areas were read in April 1983; areas 2, 3, and 4 were read in August 1983.

Establishment conditions for seeded species appeared difficult in three of the four study areas. Area 1 had severe competition from annual plants; area 2 had extreme wind-caused soil erosion (and associated seed loss); and area 3 had substantial native perennial bunchgrasses. Establishment conditions for shrubs were best in area 4 with few annuals, no noticeable soil loss, and only moderate cover of native bunchgrasses.

General conclusions are:

1. Total shrub recruitment was less than 1 percent of the PLS applied but resultant densities of all shrubs ranged from 1,726 per acre to 8,452 per acre (4 263/ha to 20 876/ha). Occupancy ranged from 1 shrub per 25 ft^2 ($1/5.8\ m^2$) to 1 shrub per 5 ft^2 ($1/1.2\ m^2$) and indicates a high level of seeding success.

2. Results suggest that seeding shrubs only at a rate of 5-10 PLS per square foot would result in an average of more than 4,000 plants per acre (9 880/ha) of winterfat and more than 1,200 plants per acre (2 964/ha) of 'Rincon' fourwing saltbush.

3. Average winterfat establishment was highest of all shrubs, but its relative advantage was greatest on the higher elevation plots.

4. 'Rincon' fourwing saltbush was intermediate in establishment success. Its highest recruitment occurred in study area 1 which was near a greasewood bottom.

5. Starter fertilizer treatments are promising; apparently enhancing recruitment in the shrub-only plots, but not in the shrub-grass plots. Big sagebrush recruitment was enhanced more (two to two and one-half times) by fertilization than that of any other shrub species.

6. Difference in recruitment between the April and August evaluations of the second growing season was not significantly different for 'Rincon' fourwing saltbush, but decreased significantly for winterfat.

7. Recruitment of shrub seedlings as a percentage of seed planted was greater where there were less seeded grasses.

8. Residual native perennial bunchgrasses exerted a strong negative influence on shrub seedling establishment and shrub cover development.

9. Land managers should carefully scrutinize the potential success of shrub establishment relative to the cost of seeding shrubs in areas with well developed stands of perennial grasses.

10. Shrub crown volume was greatest on plots with a few large fourwing saltbush seedlings; less on those plots with a large number of winterfat and big sagebrush seedlings.

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MANAGEMENT AND REHABILITATION OF A BURNED WINTERFAT COMMUNITY

IN SOUTHWESTERN IDAHO

Mike Pellant and Linda Reichert

ABSTRACT: About 3,000 acres (1 200 ha) of winterfat dominated rangeland near Boise, Idaho, were burned by wildfires in September 1981 and August 1982. This paper briefly describes the uses, ecology, and effects of fire on the Snake River Plain winterfat communities and describes the use of a hydroseeder to reseed winterfat. Seeding with a winterfat-grass mixture using a hydroseeder proved feasible but costly. Costs to reseed 500 acres (200 ha) with a hydroseeder averaged $36 per acre ($89 per ha). Advantages in using a hydroseeder include good site selectivity for application of winterfat seed and even seed distribution. However, hydroseeding is labor intensive and requires large quantities of water.

INTRODUCTION

In September 1981 and August 1982 lightning-caused fires burned 3,000 acres (1 200 ha) of winterfat (Ceratoides lanata [Pursh] J.C. Howell) dominated rangelands near Boise, Idaho. Winterfat communities provide good soil stabilization and winter forage for livestock. In addition, they provide essential prey habitat within the Snake River Birds of Prey Area. These burns occurred in an ecologically and economically important area with tremendous watershed, wildlife, and livestock values. For these reasons, two burned winterfat communities were selected for reseeding under the Bureau of Land Management's (BLM) Fire Rehabilitation Program. One thousand acres (400 ha) were seeded in November 1982; another 500 acres (200 ha) were seeded in May 1983. The authors will limit their discussion to the 500-acre (200-ha) seeding near Melba, Idaho, since accurate cost records were kept on this project.

DESCRIPTION OF AREA

The Melba treatment area is 20 miles (32 km) southwest of Boise, Idaho, in the area defined as the Snake River Plains. It is characterized by rolling hills and basaltic buttes. Elevations range from 2,840 to 3,240 feet (866 to 988 m) and slopes are less than 5 percent.

Average annual precipitation is 11.9 inches (30.2 cm) at Swan Falls Dam, 7 miles (11.3 km) south of the Melba treatment area. April through October precipitation averages 5.6 inches (14.2 cm).

April and May rainfall accounts for 70 percent of the total growing season precipitation. January is the coldest month and August is the warmest with mean monthly temperatures of 35.4°F (1.9°C) and 80.8°F (27.1°C) respectively.

Soils supporting winterfat communities are deep silty loams, well drained, and moderately permeable. These soils formed in loess or silty alluvium, thus the potential for wind erosion is severe if vegetative cover is lost. Winterfat communities occur in relatively pure stands (fig. 1) or are associated with big sagebrush (Artemesia tridentata Nutt. ssp. wyomingensis) communities in mosaic patterns. Winterfat densities in the pure stands range from 17,000 to 26,000 plants per acre (41 990 to 64 220 per ha). Understory vegetation is predominantly Sandberg bluegrass (Poa sandbergii Vasey) and cheatgrass (Bromus tectorum L.) with lesser amounts of squirreltail (Sitanion hystrix [Nutt.] J.G. Sm.) and traces of Indian ricegrass (Oryzopsis hymenoides [R&S] Ricker in Piper).

Figure 1.--Typical winterfat community near Melba seeding area.

The Melba treatment area, within the Snake River Birds of Prey Area, is renowned for its diversity and density of nesting birds of prey. An important part of this ecological system is the quality and stability of prey habitat. Some of the most important prey habitat is found in winterfat communities and associated winterfat/big sagebrush mosaics. These areas have high densities of Townsend ground squirrels

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(*Spermophilus townsendii*), a major prey species of many raptors (U.S. Department of the Interior 1979). Soils associated with the winterfat areas are well-suited for these burrowing ground squirrels.

LIVESTOCK USE

The winterfat stands along the Snake River were widely mentioned in the journals of early settlers (Keith 1938; Fulton 1965; Gibbs 1976). Winterfat or "white sage" provided good cattle feed in the winter (Shirk 1956). As range at higher elevations greened up, cattle were moved to spring and summer ranges. Sheep use followed this same pattern. This trend of winter livestock use has continued to date. Shortly after passage of the Taylor Grazing Act in 1934, allotments were established to regulate livestock numbers and establish spring-fall and winter use areas. Fencing was completed between these seasonal ranges in 1978. Since then 11,000 sheep and 7,000 cattle have grazed the allotment in which this study was conducted from December 16 to February 28 each year.

DROUGHT AND GRAZING EFFECTS

It is well documented that winterfat is drought tolerant (Hilton 1951; Hutchings and Stewart 1953; Plummer and others 1968). An extensive fibrous root system and deep taproot aid this shrub when soil moisture is limiting (Stevens and others 1977). Upon seed germination, lateral roots develop quickly in response to available moisture.

Near the Melba treatment area, nine photo-trend plots were established in 1977 to monitor drought effects on winterfat. Drought conditions were severe in 1976 and 1977. Livestock permittees took a voluntary 50 percent reduction in livestock use to lessen the grazing impacts on winterfat. In 1981 all plots were photographed again and winterfat densities compared. Only one of 80 plants present in the nine plots had disappeared between 1977 and 1981.

Grazing impacts on winterfat have also been studied. Hodgkinson (1975) reported dormant season grazing of up to 80 percent does not adversely affect vigor. However, grazing past 25 percent during the growing season will result in depleted vigor (Stevens and others 1977). Winterfat production was greatest under moderate winter stocking rates in Utah (Hutchings and Stewart 1953).

Effects of moderate winter use can be demonstrated at a winterfat grazing exclosure constructed in 1963, located within 6 miles (9.7 km) of the Melba treatment area. Canopy cover of winterfat was recorded on two permanent transects inside and outside the exclosure. Winterfat canopy cover has remained stable over the past 20 years both inside and outside the exclosure. However, vigor of ungrazed winterfat plants is visibly better than vigor of grazed plants.

FIRE EFFECTS

Whereas drought and grazing affect winterfat primarily by reducing vigor, wildfires significantly alter the composition of winterfat communities.

Frequency of fires in semidesert grass-shrub communities is normally low due to lack of fine fuels (Wright and Bailey 1983). In the Melba treatment area, herbaceous production was well above normal in 1981. Intense wildfires consumed winterfat plants to within 1 inch (2.5 cm) of ground level.

Little information is available on the effects of burning on winterfat. Dwyer and Pieper (1967) reported that winterfat resprouted vigorously after burning in New Mexico. Fire effects on winterfat were studied on a permanent transect established in April 1981, adjacent to the Melba treatment area. Four months after establishing this transect, an intense wildfire occurred. In 1982, 100 percent winterfat mortality, as determined by density measurements, was recorded on the transect. Sandberg bluegrass is now the dominant perennial species.

On different burns in this same area, winterfat mortality is 95 percent when fire is intense. Winterfat plants observed to survive these fires have at least 20 percent annual leader growth remaining. However, objective studies have not been performed to substantiate this observation.

Winterfat seed dispersal normally occurs in September, after wildfires have occurred. Thus intense wildfires normally destroy all seed on plants. Natural regeneration is rare.

Where winterfat has burned, no noticeable reproduction can be observed, even at the zone between the burned and unburned winterfat communities. Sandberg bluegrass and cheatgrass fill the space once occupied by winterfat.

SEED PRESCRIPTION

Winterfat, one native, and one introduced grass species were included in the seed prescription. Table 1 is a list of species and seeding rates used in the rehabilitation project.

Table 1.--Seed mixture applied on the Melba treatment area; seed rates are in bulk pounds per acre.

Species	Pounds per Acre
Winterfat	2.0
Russian wildrye	3.0
Indian ricegrass	.5
TOTAL	5.5

An estimated 200,000 seeds of winterfat (bulk rate) were applied at a rate of 2 pounds per acre (2.24 kg/ha). Our objective in applying winterfat

at 2 pounds per acre was to approximate prefire winterfat densities. Seed viability (determined by a germination test) was 27 percent and purity was 65 percent, yielding pure live seed (PLS) of 30,000 seeds per acre (74 100 per ha). Wasser (1982) recommends planting winterfat at rates of 1 1/2 to 3 pounds per acre (1.68-3.36 kg/ha) broadcasted in total seed mixes of 10 to 20 pounds per acre (11.2-22.4 kg/ha). Also, seeding winterfat with vigorous adapted grasses is recommended where cheatgrass is a competitor.

Russian wildrye (Elymus junceus Fisch.) has low seedling vigor (Wasser 1982); thus it does not provide serious first year competition to winterfat seedlings. This grass also has several desirable traits for prey populations in the area. It greens up early in spring and any regrowth in the fall stays green longer than other commonly seeded grasses (Wasser 1982).

Indian ricegrass was included since it was originally the dominant grass on the winterfat sites (Boise District Range Site Description[1]). Currently, Indian ricegrass is present in trace amounts, primarily near anthills.

Broadcast seeding and covering winterfat seed less than one-quarter inch (0.64 cm) is recommended by several authors (Springfield 1970; Stevens and others 1977). Ferguson and Frischknecht (1981) found autumn broadcasting of winterfat followed by harrowing resulted in a fair stand of winterfat despite some winter mortality. Other authors also recommend fall planting of winterfat (Hodgkinson 1975; Fisser 1981). Statler (1967) and Stevens (1981) had success with spring planting of winterfat.

USE OF HYDROSEEDER

Originally, grass and winterfat seed were to be premixed and broadcast from a Simplex (Model 1620) hydraulic-driven seeder mounted on a helicopter. This proved unfeasible. The light winterfat seed and pieces of stems bridged in the hopper resulting in an effective seeding rate of less than 1 pound per acre (1.12 kg/ha). Also, grass seed had a tendency to settle to the bottom of the hopper. Similar problems were encountered when trying to broadcast winterfat seed with a modified insulation blower or planting it with a rangeland drill. Planting depths of less than one quarter inch (0.64 cm) are not possible with the standard rangeland drill even with depth bands on the disks.

With alternatives exhausted and proper seeding time at hand, a Finn "Bantam 8" hydroseeder was selected to seed the treatment area. No reference was found to indicate this piece of equipment had been previously used to rehabilitate large acreages of disturbed rangeland. Stevens (1981) recommended against using a hydroseeder in arid land seedings because seed is not covered with soil. Therefore, our seed mixture was covered after hydroseeding by pulling a pasture-type harrow one way over the seeded area.

Several modifications to the hydroseeder were required prior to field work. First, the hydroseeder was mounted on a gooseneck trailer and securely chained and boomed. A 1-ton, four-wheel drive pickup pulled the trailer-mounted hydroseeder (fig. 2).

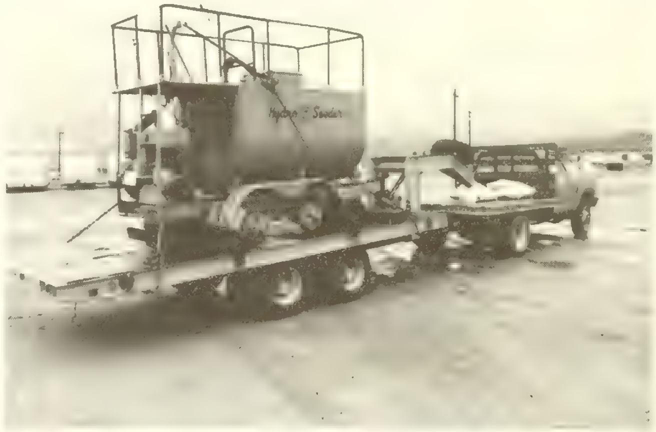

Figure 2--Hydroseeder modified for rangeland seeding.

The hydroseeder tank was filled with 800 gallons (3 030 liters) of water, the agitator blades inside the tank started, and seed added. The grass/winterfat mixture was then forced out a nozzle under pressure. Typically, each 800-gallon load of water and seed could be distributed over 15 acres (6 ha) in 10 minutes. Windspeeds less than 10 miles per hour (16 km/h) and an average vehicle speed of 5 miles per hour (8 km/h) were required to obtain this result. When slopes exceeded 10 percent, topography was broken, or windspeeds exceeded 10 miles per hour (16 km/h), acreage seeded decreased proportionately. Under ideal conditions a swath 120 feet (37 m) wide could be seeded with the hydroseeder.

About 31,000 gallons (117 300 liters) of water were required to seed 500 acres (200 ha). Two trucks with drivers were required to keep the hydroseeder supplied with water. Water was hauled to the treatment area in a 4,000-gallon (15 100-liter) trailer pulled by a semi-truck. Water was pumped from the trailer to a more mobile 2,800-gallon (10 600-liter) water truck which followed the hydroseeder. Access to the treatment area was on good, improved dirt roads for the 34-mile (54.7-km) round trip to obtain water at Kuna, Idaho.

[1]Boise District Range Site Descriptions. Data on file at BLM, Boise District Office, Boise, Idaho; 1982.

A three-person crew was required to operate the hydroseeder. One person drove the truck pulling the hydroseeder, another operated the hydroseeder controls which distributed the seed mixture, while the third gave the truck driver directions over a two-way radio. The "guide" on the hydroseeder deck was necessary to insure that the truck driver would keep the proper distance from the previously seeded areas. From the deck of the hydroseeder, 20 feet (6 m) above the ground, previous passes were easily recognized by wet soil, or presence of white winterfat seeds on the blackened soil.

COSTS

Hydroseeding proved to be expensive (table 2). Costs to reseed 500 acres (200 ha) averaged $36 per acre ($89 per ha).

Table 2.--Average cost to reseed 500 acres with a winterfat-grass mixture near Melba, Idaho.

Item	Cost per acre	Percent of total cost
Planning and survey/design [1]	$ 4	8
Seed [2]	21	59
Hydroseeder operation [3]	7	23
Harrowing	4	10
TOTALS	36	100

[1]Includes costs to prepare the fire rehabilitation plan, flag the treatment area, prepare equipment, and organize personnel.

[2]Costs per pound for the three species: (1) winterfat - $7.25 ($15.95 per kg); (2) Russian wildrye - $0.71 ($1.56 per kg); and (3) Indian ricegrass - $7.67 ($16.87 per kg).

[3]Includes salaries, equipment, mileage, maintenance, and purchase of water. Equipment costs would have been higher if all equipment needed for the project, including the hydroseeder, had not been available within BLM.

By comparison, aerial seeding with a helicopter costs $4-5 per acre ($10-12.50 per ha). All other costs, i.e. planning and survey/design, seed costs, and harrowing are required with aerial seeding as well as hydroseeding. Thus seeding costs are $2-3 per acre ($5-7.50 per ha) higher with a hyrdoseeder than with a helicopter.

ADVANTAGES AND DISADVANTAGES

As with all seeding techniques, especially untested ones, advantages and disadvantages were encountered.

Advantages of applying winterfat with a hydroseeder include:

1. Low seeding rates of a winterfat-grass mix (5.5 pounds per acre; 4.9 kg per ha) could be efficiently applied. Neither a rangeland drill nor an aerial seeder proved feasible in this situation.

2. Site selectivity for application of winterfat seed is good. Rocky areas, prefire sagebrush sites, and small unburned winterfat islands can be avoided, thus promoting the most efficient placement of expensive winterfat seed. This is especially important in complex winterfat/big sagebrush mosaics.

3. Seed distribution is uniform. The continuous mixing action of the hydroseeder promoted even seed distribution.

4. Winterfat causes an allergic reaction in many people. Using a hydroseeder with water as the dispersal agent alleviated this problem.

Disadvantages of hydroseeding include:

1. Hydroseeding in a rangeland situation is labor-intensive, requiring a five-person crew.

2. Equipment, especially the hydroseeder, is not designed for seeding rangelands. Extra precautions and maintenance are required to keep equipment in good working condition.

3. Winterfat seed must be screened to remove all stems greater than one-quarter/inch (0.64 cm) in length. The hydroseeder pump is susceptible to clogging. Cleaning the pump takes 30 to 45 minutes, during which time the seed/water mixture can be lost. However, stems created problems in all seeding methods tested.

4. Weather conditions and terrain affect the speed and efficiency of the operation. Winds greater than 10 miles per hour (16 km/h) significantly limit the width and distribution of seed. Slopes greater than 10 percent place the hydroseeder at too great an angle. The hydroseeder weighs about 9,000 pounds (4 090 kg) when filled with water and is top heavy when mounted on a trailer.

5. Water must be relatively close to the treatment area and on easily accessible roads. Using the hydroseeder when temperatures may drop below freezing necessitates draining and winterizing pumps each night.

SUMMARY

Using a hydroseeder to reseed large acreages of rangeland is unlikely to become a widely used rehabilitation technique. Costs, equipment

required, and manpower needs all preclude the use of a hydroseeder except in specialized situations, i.e., applying winterfat seed in a mosaic vegetation pattern. Other more efficient and less costly techniques to plant winterfat should be developed.

Regardless of the problems associated with seeding winterfat, an effort must be made to save this valuable range, wildlife, and watershed resource in southwestern Idaho. The alternative is replacement of winterfat with much less desirable herbaceous species.

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METHODS AND COSTS FOR ESTABLISHING SHRUBS ON MINED LANDS IN SOUTHWESTERN WYOMING

Forrest Luke and Stephen B. Monsen

ABSTRACT: Several methods were investigated to determine the most cost-effective means for establishing various shrub species on reclaimed surface-mined land at the Black Butte Coal Mine in southwestern Wyoming. Direct seeding was far more cost-effective ($0.18/surviving shrub) than any transplanting method. Transplanting bareroot stock was the most economical transplanting method at $0.41/surviving shrub. Hand transplanting and front-end loader transplanting of mature indigenous shrubs provided excellent plant survival, but incurred high costs ($2.24 and $5.79 per surviving shrub respectively). Shrub species indigenous to the mine site demonstrated the highest adaptability and long-term survival potential. The majority of adapted shrub species were chenopods.

INTRODUCTION

One of the most difficult and often costly aspects of revegetating disturbed lands is shrub establishment. Plant materials adapted to site specific climatic and soil conditions must be selected if establishment is to be successful (DePuit and others 1980; Stevens 1981). In addition, methods that are operational and cost effective should be used to establish the desired shrub density.

Many factors contribute to the success or failure of establishing plants on reclaimed lands. Some, such as soil structure, soil texture, temperature, and average windspeed, are important but cannot be manipulated. Others, such as supplemental irrigation, soil amendments, proper seedbed preparation, and effective ground mulch, can be used to enhance success. The manner in which cultural practices are employed is critical to the success of any revegetation project.

Frischknecht and Ferguson (1979) reported that areas which receive less than 10 inches (25 cm) of annual moisture must be treated with special care if shrubs are to be established by direct seeding. Transplanting bareroot or container stock can often improve shrub establishment. However, plant survival and adaptation are significantly influenced by availability of soil moisture, competition from weedy plants, planting techniques, and fertility of the soil media (Van Epps and McKell 1980). The survival and growth of woody transplants are also dependent on, or influenced by, the presence of mycorrhizae (Cundell 1977). Few woody species are adapted to arid regions and can survive direct seeding or transplanting. Crofts and Carlson (1982) recommend using mature wilding transplants to improve the establishment and natural spread of woody species.

Shrub density standards currently proposed for surface coal mines in Wyoming would require that 450 shrubs per acre (1 110/ha) be established over 90 percent of reclaimed lands, while 4,050 shrubs per acre (10 000/ha) would be required on the remaining 10 percent. These standards are designed to restore wildlife habitat. Therefore, reclamation personnel know precisely what shrub density and diversity standards must be met. They, thus, have the task of selecting the most effective and economical methods to reach those standards. The purpose of this paper is to compare the costs and feasibility of various shrub establishment methods and to report the success of several native shrub species in relation to the methods employed.

STUDY AREA

The study was conducted on reclaimed surface mined lands at the Black Butte Coal Company, Sweetwater County, Wyo. The mine is located approximately 40 miles (64 km) east of Rock Springs at an elevation of approximately 6,600 feet (2 012 m).

The climate is semiarid; mean monthly temperatures range from 66 F (17 C) in July to 20 F (-6 C) in January. Average annual precipitation is approximately 7.5 inches (18 cm), with highest amounts coming from April to June. Moisture received during the October 1981 to September 1982 period was 7.6 inches (19 cm). Moisture was rather evenly distributed throughout the period.

Topography consists of rolling hills with occasional sandstone rock outcrops or cliffs. The study area is drained by Bitter Creek, which flows into the Green River. Undisturbed soils are generally sandy loam in texture. Soil pH generally ranges from 7.0 to 8.0. Salt content varies by site location.

Native vegetation is characteristic of the cold salt-desert shrub community interspersed with sagebrush steppe. Chenopod shrubs and big sagebrush (Artemisia tridentata Nutt.) are the

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dominant woody plants. Common chenopod shrubs include Gardner saltbush (Atriplex gardneri[Moq.] D. Dietr), shadscale (Atriplex confertifolia [Torr. & Frem.] Wats.), and black greasewood (Sarcobatus vermiculatus [Hook] Torr.). Principal grasses are thickspike wheatgrass (Agropyron dasystachyum [Hook] Scribn.), Sandberg bluegrass (Poa sandbergii Vasey), and Salina wildrye (Elymus salina Jones).

METHODS

Four different methods of shrub plantings were evaluated in the study: (1) direct seeding, (2) transplanting of 1-0 size bareroot stock, (3) transplanting mature wildings, and (4) transplanting shrub pads using a front-end loader.

Study sites totaling 257 acres (104 ha) were located on regraded overburden dumps during the spring of 1981. The recontoured surface was topsoiled with approximately 8 inches (20 cm) of subsoil and 4 inches (10 cm) of topsoil material. Fertilizer was added at the rate of 40 lb/acre (45 kg/ha) available nitrogen in the spring of 1982 and 75 lb/acre (84 kg/ha) available phosphorus in the fall of 1981.

Direct Seeding

Five shrub species were seeded in conjunction with several grass species and common alfalfa (Medicago sativa L.) in late October 1981 (table 1). Small and/or chaffy seed including winterfat (Ceratoides lanata [Pursh] J. T. Howell), big sagebrush, and rubber rabbitbrush (Chrysothamnus nauseosus [Pall.] Britt.) were broadcast seeded with a large fertilizer spreader and covered by cultipacking. Large-seeded species, including all herbs and the shrubs fourwing saltbush (Atriplex canescens [Pursh] Nutt.) and Gardner saltbush were then drill seeded with a rangeland drill (table 2).

Table 1.--Seed mixture planted at the Black Butte Coal Mine, Sweetwater County, Wyo. 1981.

Species planted	Seeding rate (pounds pure live seed/acre)
Agropyron dachystachyum (thickspike wheatgrass)	3.0
Agropyron spicatum inerme (beardless bluebunch wheatgrass)	2.0
Oryzopsis hymenoides (Indian ricegrass)	3.0
Medicago sativa (common alfalfa)	0.5
Atriplex canescens (fourwing saltbush)	1.0
Atriplex gardneri (Gardner saltbush)	1.0
Artemisia tridentata (big sagebrush)	0.2
Ceratoides lanata (winterfat)	1.0
Chrysothamnus nauseosus (rubber rabbitbrush)	0.3
TOTAL	12.0

Grass seed, comprised of several improved cultivars, was seeded at an intermediate rate of 8 pounds pure live seed (PLS)/acre (9 kg/ha) to reduce initial grass competition to shrub establishment, and yet provide community diversity. A diverse seed mixture was used to assure that one or more species would be adapted to every combination of topography, aspect, and soils. Shrubs were seeded at a rate of 3.5 PLS lb/acre (8 kg/ha). Following seeding, straw mulch was applied at a rate of 2 ton/acre (4 500 kg/ha). A drip irrigation system was installed in late June 1982,

Table 2.--Cost and establishment success of shrub species by direct seeding at Sweetwater County, Wyo.

Species	Seeding rate [1]PLS lb/acre	Seeding rate number PLS/acre	Seed plus seeding cost/acre	Established seedlings/ 1,000 PLS	Established seedlings acre	Cost/seedling
Atriplex canescens	1.0	52,000	$20.00	3.30	169	$0.12
Atriplex gardneri	1.0	110,000	35.00	1.80	199	0.18
Artemisia tridentata	0.2	500,000	19.00	0.01	6	3.17
Ceratoides lanata	1.0	110,000	35.00	2.80	308	0.11
Chrysothamnus nauseosus	.3	130,000	28.00	0.50	69	0.40
TOTAL	3.5	902,000	$137.00		751	
AVERAGE				[2]0.83		[3]$0.18

[1]PLS = pure live seed

[2]Average number of established seedlings per 1,000 PLS determined by:

$$\frac{\text{(Total no. established seedling x 1,000)}}{\text{Total number PLS planted}}$$

[3]Average cost per seedling determined by:

$$\frac{\text{Total acre planting costs}}{\text{Total number established seedlings}}$$

but because of late installation, irrigation appeared to have little effect on plant establishment.

Shrub seedling establishment density was evaluated by systematic placement of 26 belt transects, each 3.28 by 82 feet (1 by 25 m), in September 1982. All shrubs rooted within the belt transects were counted toward shrub density. Shrubs per transect area were converted to shrubs per acre with all 26 transects averaged to arrive at the final density figure. The cost per shrub was based on the cost of the seed plus planting costs, divided by the number of shrubs to become established.

Bareroot Transplanting

Shrub seedlings of 10 species (table 3) were hand transplanted from 1-0 bareroot stock in early April 1981 to test their adaptability and survival. Shrubs were planted approximately 6 feet (2 m) apart in rows of up to 25 plants. The planting site was a shallow swale with east- and west-facing slopes. Shrubs were planted on both slopes and in the swale bottom. Soil pH ranged from 7.5 to 8.0. Soil texture was sandy loam. Depth of replaced topsoil was approximately 12 inches (30 cm).

Shrubs were transplanted onto areas that had been fall seeded with the grass-herb mixture (table 1). Understory grasses and broadleaf herbs were not eliminated prior to shrub transplanting, and no attempts were made to control weedy competition during the growing season. Density and ground cover were determined for all understory herbs in October 1982.

Shrub survival was evaluated in October 1982. Different accessions of the same shrub species were evaluated together for this report. The cost per surviving shrub was based on the estimated cost of bareroot plant material plus planting costs. The cost per planted shrub ($0.20/plant) was divided by the percent survival to arrive at the cost per surviving shrub.

Mature Wilding Transplanting

Individual mature healthy plants of five shrub species (table 4) were hand transplanted in mid-May 1982 on a reclaimed overburden dump to evaluate costs and survival and ultimately to test the regeneration potential of shrubs by seed dispersal from mature plants. The study site was located on an approximate 20 percent slope with a north aspect. Reapplied topsoil was approximately 15 inches (38 cm) deep. Soil pH ranged from 7.0 to 7.5. Plants were excavated offsite by hand. Roots were excavated to a minimum of 12 inches (30 cm) and as much soil as possible was left attached to the roots. Shrubs were planted approximately 50 feet (15 m) apart so that each plant would have a relatively large area in which seed could eventually be dispersed. The wildings were transplanted onto sites that were fall seeded with a grass-herb mixture (table 1). Seeded herbs and weedy plants were not controlled during the growing season. Transplanting costs consisted of labor and shrub transport. Plant survival was evaluated in October 1982.

Front End Loader Transplanting

Groups of mature shrubs (pads) were excavated offsite and transplanted onto three recontoured and retopsoiled overburden dump sites in mid-May 1982. A Caterpillar 992C front-end loader with a 12-yd^3 (9 m^3) coal bucket was used to dig and replant the pads. Pads were transplanted by first removing approximately 2 to 3 feet (.6 to 1.0 m) overburden

Table 3.--Cost and first-year survival of bareroot transplants at Sweetwater County, Wyo.

Species	Number individuals transplanted	Number surviving individuals	Survival (%)	Cost/ surviving plant
Amelanchier alnifolia	50	32	64	$0.31
Artemisia nova	44	42	95	0.21
Atriplex canescens	25	21	84	0.24
Chrysothamnus nauseosus	25	7	28	0.71
Ephedra nevadensis	50	6	12	1.67
Ephedra viridis	50	18	36	0.50
Grayia spinosa	25	10	40	0.50
Purshia glandulosa	25	5	20	1.00
Purshia tridentata	125	68	54	0.37
Rhus trilobata trilobata	25	8	32	0.62
TOTAL	444	217		
AVERAGE			[1]49	[2]$0.41

[1] Average plant survival determined by: $\frac{\text{number surviving plants}}{\text{total number planted}}$

[2] Average plant cost per surviving shrub determined by: $\frac{\text{cost per planted shrub (\$0.20)}}{\text{percent survival}}$

Table 4.--Cost and first-year survival of mature wilding transplants at Sweetwater County, Wyo.

Species	Number individuals transplanted	Number individuals surviving	Survival (%)	[1] Cost per surviving plant
Artemisia tridentata	25	25	100	$2.19
Atriplex confertifolia	25	24	96	2.28
Chrysothamnus nauseosus	25	24	96	2.28
Chrysothamnus viscidiflorus	34	34	100	2.19
Sarcobatus vermiculatus	31	30	97	2.26
TOTAL	140	137		
AVERAGE			[2] 98	[3] $2.24

[1] Transplanting costs distributed evenly among all species.

[2] Average survival determined by: $\frac{\text{number surviving plants}}{\text{total number planted}}$

[3] Average cost surviving plant determined by: $\frac{\text{cost per planted shrub}}{\text{percent survival}}$

with the front-end loader bucket and then replacing approximately the same amount of soil in which shrubs were rooted. Each pad was approximately 6 by 12 feet (1.8 by 3.6 m). The procedure required one person to operate the loader and another to direct the operator. The most difficult aspect of the front-end loader transplanting operation was removing the shrub pad from the bucket and placing it on the ground so that all shrubs remained vertical without exposing the roots.

A total of 232 shrubs of various species were evaluated in shrub pads totaling approximately 3,000 feet^2 (71 m^2) in October 1982. Transplanting costs included labor and front-end loader operation costs.

RESULTS AND DISCUSSION

Direct Seeding

Shrub density data collected on the 257-acre (104-ha) study site are presented in table 2. Direct seeding produced an average shrub density of 751 shrub seedlings per acre (1 856/ha) which translated to an average return of 0.83 shrub for each 1,000 pure live seeds planted (table 2). Chenopod shrubs comprised over 90 percent of all established seeds. Fourwing saltbush and winterfat were the most successful at producing seedlings relative to the number of seeds planted. Fourwing saltbush provided a return of 3.3 seedlings per 1,000 seeds planted, whereas a figure of 2.8 was recorded for winterfat. Winterfat established the most seedlings per acre, but was seeded at a heavier rate. Establishment of rubber rabbitbrush and big sagebrush was very poor.

Seedling germination and emergence of the seeded shrubs occurred in early May. Most seedlings appeared by mid-June. No germination occurred after this date.

Seeded grasses occupied less than 3 percent ground cover during the period of shrub establishment. The seeded perennials did not appear to influence shrub seedling survival. Annual kochia (*Kochia scoparia* [L.] Schrad) and halogeton (*Halogeton glomeratus* C.A. Mey.) germinated and established on the site in the early summer. However, the presence of these two late-germinating weedy species appeared to have had little effect on shrub seedling survival.

Moisture received prior to and during the period of germination was not above normal. Less than 0.8 inch (2.0 cm) was received in May and less than 0.4 inch (1.0 cm) was recorded in June.

Two chenopod species that were not seeded with the regular seed mixture that show promise at the mine site are shadscale and black greasewood. Both species were hand broadcast into swales that were created on the recontoured surface of the study site. Plants established very well, although no quantitative data were taken. Both species will be added to mine seed mixtures beginning in the fall of 1983.

Several practices could be implemented at Black Butte Coal Company that would increase success of direct seeding. Improving the timing and application efficiency of irrigation may improve germination and subsequent seedling survival of seeded shrubs. However, care must be taken that improved grass establishment and competition, as a result of irrigation, does not hinder the slower growing shrub seedlings. Planting grass seed at moderate rates and seeding relatively small patches exclusively to shrubs are other potential means to promote better shrub establishment.

In this study, shrubs were established at a much lower cost by direct seeding than by any method of transplanting. The average cost per shrub from direct seeding ($0.18/established shrub) was only about one-half the cost ($0.41) of the least expensive transplanting method (bareroot transplanting). Direct seeding was also faster and easier to implement.

Establishing shrubs from seed does have limitations, however. Perhaps the biggest limitation is that establishment is very erratic, depending on climatic and edaphic conditions. Adaptability, quality, and availability of native shrub seed can also create problems. Finally, the difficulty of establishing certain species from seed using current methods of seeding makes it almost imperative that such species be transplanted if they are to be established.

Bareroot Transplanting

First year survival and cost per surviving plant for ten shrub species are presented in table 3. Total average survival (49 percent) is slightly misleading; several of the species tested appeared to be poorly adapted to mine site conditions. Although skunkbush sumac (Rhus trilobata Nutt.), desert bitterbrush (Purshia glandulosa Currant.), antelope bitterbrush (P. tridentata [Pursh.] DC), and Saskatoon serviceberry (Amelanchier alnifolia [Nutt.] Nutt.) demonstrated relatively good survival (42 percent), most transplants generally were not vigorous and long-term survival appeared tenuous.

Two species, black sagebrush (Artemisia nova A. Nels.) and fourwing saltbush, demonstrated excellent first-year survival and were also very vigorous. Rubber rabbitbrush and spiny hopsage (Grayia spinosa [Hook.] Moq.) had relatively poor survival, partially as a result of poor transplanting stock, but surviving plants were growing well and appeared to be well adapted. The mean survival among these four adapted species was 63 percent.

Cost per surviving shrub incurred for the establishment of the four adapted shrubs was $0.36. Since transplant survival was considerably higher for these four species, costs per established shrub are reduced. Costs could be further reduced if adapted and healthy stock was utilized.

Nearly all transplant losses occurred immediately after planting. Failure to establish accounted for the major loss among all species. Although the sites received only a normal amount of moisture, few transplants appeared to be under stress during mid-summer. Competition from seeded species and weeds did have some influence on less adapted species. Weedy competition was not evident during the latter part of the growing season.

Van Epps and McKell (1980) suggested that bareroot plantings should be observed for a minimum of 3 to 4 years before transplanted shrubs can be considered permanently established. Crofts and Carlson (1982) determined the average survival rate of bareroot transplants at a number of mines in the Western States was 62 percent for the first year, but dropped to 45 percent at the end of 5 years. Thus, the 63 percent first-year survival rate of the four shrub species in this study is similar to that cited by Crofts and Carlson.

The economics of bareroot transplanting should be based on the use of adapted shrub accessions and the most efficient planting methods available. Selecting adapted shrub accessions must be done through the use of selection test plots and site-specific revegetation experience. The most cost efficient manner of transplanting would appear to be contracting with an experienced tree planting company. Whether mechanical or hand planting methods are used would depend upon topographic conditions.

From a cost standpoint, bareroot transplanting was more effective than either mature wilding transplanting ($2.24 plant) or front-end loader transplanting ($5.79/plant), but was less cost effective than direct seeding. Transplanting could be used to supplement direct seeding and to increase shrub diversity by adding adapted species that do not establish well from seed, or to increase the density of shrubs above that achieved by direct seeding.

Mature Wilding Transplanting

Table 4 presents first-year survival rates and cost per surviving plant for the five species transplanted as mature wildings. Survival for all species approached or equaled 100 percent. However, the technique is labor-intensive and the cost per established plant may prohibit its use. Methods of planting must be determined by other criteria important to individual mine companies.

A final determination of the effectiveness of hand transplanting indigenous plant material must wait for a minimum of two or more growing seasons to evaluate regeneration of shrubs by seed dispersal from sexually mature plants. If successful, seedling establishment could substantially lower costs of shrub establishment.

Transplanting Pads

Table 5 summarizes the costs and first-year survival of seven shrub species transplanted in pads with a front-end loader. All of the transplanted species demonstrated high survival. Surviving plants were vigorous and the potential for long-term survival appeared to be excellent. Soils were moist at the time of transplanting. However, the sites did not receive an unusual amount of moisture prior to or immediately after planting. Pads were adequately placed to eliminate drying of the soil.

Despite the success of transplanting shrub pads with a front-end loader, high costs associated with the technique may limit its use for large-scale shrub establishment. Costs could possibly be reduced 50 percent through increased transplanting efficiency. This is a reasonable expectation with additional experience. However, the cost per established shrub would still be many times higher than that for direct seeding or bareroot transplanting.

However, placement of mature shrub pads offers many advantages. Shrub pads include topsoil with active microorganisms, insects, native forbs, and grasses

Table 5.--Cost and first-year survival of front-end loader transplants at Sweetwater County, Wyo.

Species	Number individuals transplanted	Number individuals surviving	Survival (%)	Cost/ surviving plant
Artemisia spinescens	11	7	64	$7.05
Artemisia tridentata	86	67	78	5.79
Atriplex confertifolia	18	15	83	5.39
Atriplex gardneri	4	4	100	4.49
Chrysothamnus viscidiflorus	15	15	100	4.49
Grayia spinosa	90	64	71	6.32
Sarcobatus vermiculatus	8	8	100	4.49
TOTAL	232	180		
AVERAGE			[1]78	[2]$5.79

[1]Average survival determined by: $\frac{\text{number surviving plants}}{\text{total number planted}}$

[2]Average plant cost per surviving plant determined by: $\frac{\text{cost per planted shrub}}{\text{percent survival}}$

that are capable of spreading into adjacent areas. They provide immediate wildlife habitat and islands for shrub seed dispersal (Crofts and Carlson 1982), and they can be used to stabilize drainage channels and to provide esthetic diversity. Additional shrubs may be gained by seed dispersal which would decrease shrub establishment costs.

The best time to schedule loader transplanting is after recontouring of overburden has been completed and before topsoil is replaced. This sequence eliminates disturbance of reclaimed soils and plants. In addition, shrub pads should normally be taken from sites where topsoil is to be stripped, preferably sites in close proximity to the recontoured area.

SUMMARY AND CONCLUSIONS

Several methods of establishing native shrubs on reclaimed surface-mined land at Black Butte Coal Company in southwestern Wyoming were investigated. The survival success, apparent adaptability of various shrub species, and costs of establishment were also discussed in relation to the shrub establishment techniques.

Data in this report represent first-year shrub establishment results and thus are preliminary. However, differences in the cost for establishing shrubs among methods were sufficiently large to suggest some general conclusions.

Direct seeding appears to be the most cost efficient method for establishing most shrubs evaluated on the study area. Establishment of shrubs from bareroot transplants was found to be less cost effective than direct seeding, but more effective for establishing certain shrub species. Bareroot transplanting may be used to supplement direct seeding for increasing shrub diversity or, as regulations dictate, to increase overall shrub density.

Methods for transplanting excavated mature indigenous shrub species, although very successful, were found to be the most expensive. However, these methods could be implemented for certain site specific uses. Natural spread of seed from the transplanted sites may eventually occur, and would thereby reduce the cost of establishing desirable shrubs.

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PERFORMANCE OF CHENOPODIACEAE SPECIES ON PROCESSED OIL SHALE

Neil C. Frischknecht and Robert B. Ferguson

ABSTRACT: In 1976, shale revegetation studies began at Sand Wash in Utah's Uinta Basin. Several chenopod species were seeded and/or transplanted onto processed oil shale sites to determine viability. Soil depths, types, and irrigation were varied by plot. At site 1, highest survival rates were by Atriplex obovata Moq., Atriplex bonnevillensis C. A. Hanson, and Kochia prostrata (L.) Schrad. Kochia prostrata and Camphorosma monspeliacum L. were most prolific. At site 2, Atriplex gardeneri and Kochia prostrata had the highest survival rate, followed by the hybrids A. cuneata, A. idahoensis, and A. aptera.

INTRODUCTION

Forest Service research on revegetation of processed oil shale began in the spring of 1976 at two major sites: Sand Wash, in the salt-desert shrub zone of eastern Utah's Uinta Basin, and Davis Gulch, in the upper mountain brush zone of western Colorado. The Sand Wash site is located approximately 32 miles (51 km) south of Vernal, Utah, on land owned by the State of Utah and leased to The Oil Shale Company (TOSCO). The Davis Gulch site is on land owned by the Colony Development Corporation, of which TOSCO is a partner.

Previous research showed that TOSCO II processed oil shale is highly saline, highly alkaline, low in available P and N, and relatively low in available K, with a texture similar to silt loam (Schmehl and McCaslin 1973). Unleached processed shale had a saturation extract conductivity of 13.0 mmhos/cm (Berg 1973). Heavy leaching with water in the amount of 47 to 60 inches (119 to 152 cm) was required to reduce the saturation extract conductivity to within a range suitable for grasses to grow.

Our approach included the use of salt-tolerant shrubs of the Chenopodiaceae family that did not require leaching of salts for plant survival and growth. Two studies at the Sand Wash site involved 28 Chenopodiaceae species or accessions, most of which belonged to the genus Atriplex. Other genera included Ceratoides, Grayia, Sarcobatus, Kochia, and Camphorosma. Species of the latter two genera were introduced from the Soviet Union. At Davis Gulch, only Atriplex canescens (Pursh) Nutt. and Kochia prostrata (L.) Schrad. were tested along with several non-Chenopodiaceae species (Ferguson and Frischknecht 1983). At this higher elevation, the two chenopod species exhibited excellent growth under all treatments and were the most outstanding on processed shale.

PLANT DESCRIPTIONS

Descriptions of three introduced species used in these studies are presented here as derived from Komarov (1936). Descriptions of the other species may be found in Blauer and others (1976) and Stutz[1]. Kochia prostrata (L.) Schrad., a polymorphic undershrub native to Eurasia, is 4 to 30 inches (10 to 75 cm) high with ascending branches covered with short, crisp hairs. Leaves are linear to filiform, flat, and hairy. The inflorescence is spiciform or paniculate; glomerules are remote, mostly in groups of three or four. Perianth is hairy. Dorsal appendages of fruiting perianth are reddish, either rounded, flat, tuberclelike, or oblong winglike, narrowing toward the base, and are scarious, with darker nerves, and rounded toothed on the margin. Seeds are rounded-oval to subrotund, about .075 inch (2 mm) in diameter, with a prominent annular embryo, convex at the center on both sides, brown, naked, and smooth. Kochia prostrata flowers from July to September. The plant grows on clay soils, stony slopes, chalk, sandy steppes, and sandy plains. It is used for fuel by nomads in semi-desert and desert regions. It is eaten readily by horses, camels, sheep, and goats. In its native habitat, the plant is often found growing in association with the crested wheatgrasses (Agropyron cristatum and A. desertorum).

Kochia prostrata var. villosissima Bong. et Mey. Verz. is a white villous race associated with sandy habitats of the semi-desert zone.

Camphorosma monspeliacum L. is described as a dense caespitose undershrub 4 to 20 in (10 to 50 cm) high. Annual shoots having short crisp hairs

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[1]Stutz, H. C. Breeding superior plants for disturbed lands. Unpublished paper presented at Weglen Mined Land Rehabilitation Workshop, Fort Collins, Colorado. June, 1982.

are borne on the woody branches. Leaves are subulate, .118 to 0.4 inches (3 to 10 mm) long, erect or more rarely recurved. Flowers are solitary in a short compact spire, the subtending bracteoles as long as or shorter than the flowers. Perianth is .118 to .38 inches (3 to 35 mm) long densely covered with hairs. Seeds are oval or oblong, brown or brownish black, and diffusely glandular. Camphorosma monspeliacum is found on clay soils, also gravelly slopes. According to Komarov (1936), the plant contains about 0.2 percent volatile oils with the scent of bitter almonds which yield propylamine upon distillation with KOH. The plant has an odor of camphor and has been used for medicinal purposes as a stimulant, diuretic, and diaphoretic. It is used as forage for camels, sheep, and goats in desert regions. We have not detected the camphor odor, nor have we made chemical analyses of the plant. We observed that this species was eaten more readily than others by cottontail rabbits that got inside the enclosure at Sand Wash.

Seed that came to us as Ceratoides papposa (no author) in 1975 from the Agriculture Research Service in Logan, Utah was a derivative of an introduction PI 371860, Eurotia ceratoides (L.) C.A.M. from Russia in 1972. Russian literature (Komarov 1936) describes this species as a small shrub 15.7 to 39 inches (40 to 100 cm) high; leaves entire, 1-nerved, oval, oblong, ovate-lanceolate, or linear-lanceolate with a short petiole. The fruit is obovoid, about .118 inch (3 mm) long, covered with oppressed hairs and some stellate hairs. Flowering occurs July to September. In its native habitat, the plant is gathered for fuel in local regions and is eaten by camels. Its economic importance was greatest in the Pamir high deserts.

Robertson (1982) has described a separate (1962) introduction of Eurotia ceratoides (L.) C.A.M. (Pamirian winterfat) from the U.S.S.R. Pamir Research Station and Academy of Science as a promising species for arid ranges in Nevada. It is described as being a highly variable and pliable species with several races being identified.

SAND WASH STUDIES

Site 1

The first study at Sand Wash involved testing 15 accessions of plants on different depths of soil covering processed shale, ranging from no covering over shale to soil 3 feet (0.91 m) deep over processed shale. Approximately 375 tons (340 metric tons) of TOSCO II processed shale were transported by trucks from Colony Development operations at Parachute, Colo., to the site at Sand Wash. The shale was spread and compacted approximately 2.5 feet (0.76 m) deep in a V-shaped ravine that had been prepared for that purpose (fig. 1). Soil that had been removed in shaping the ravine was spread over the center portion of the shale in the form of a double-edged wedge varying in depth from 0 at the two outside edges to 3 feet (0.9 m) in the center of a linear area 40 feet (12 m) wide and 75 feet (23 m) long.

Dividing the area lengthwise in the center allowed for four strips, each 5 feet (1.5 m) wide, on each side of the center line. These were used as four treatments having different depths of soil over processed shale from the outside edges towards the center as follows:

1. No soil covering processed shale, but 2.5 inches (6.35 cm) of sewage sludge rotovated into the top 8 inches (20 cm) of the shale.

2. Processed shale covered with 0 to 1 foot (0 to 30.5 cm) of replaced soil.

3. Processed shale with 1 to 2 feet (30.5 to 61 cm) of soil covering.

4. Processed shale with 2 to 3 feet (0.61 to 8.91 m) of soil covering.

Plots were small (2.5 by 5 ft [0.76 by 1.5 m]) with four replications in a randomized-block split plot design. Plants that had been grown in containers in the greenhouse for approximately 4 months were transplanted in the field on May 4, 1976. Supplementary water was added by drip irrigation to two replications on five occasions during the first summer, and twice the second summer. The drip irrigation system applied water at the rate of 1 gallon (3.8 liters) per hour to each plant, but it ran for only 15 minutes on most occasions. Twice the first summer, water was applied for 30 minutes at a time.

Site 2

The second study at Sand Wash involved a comparison of container-grown transplants with plants from direct seeding, and also a comparison of two different types of soil covering over shale.

In late September 1976, 475 tons (431 metric tons) of processed shale were transported by truck from the Colony Development site at Parachute Creek, Colo., to an experimental site at Sand Wash a short distance from the first site. The top 8 to 12 inches (20 to 30 cm) of soil from an area 50 feet (15.2 m) wide and 100 feet (30.5 m) long at the end of a small basin was stockpiled, and the area was leveled for placement of the processed shale. The processed shale was spread over the area to a depth of approximately 30 inches (0.76 m). Washed gravel about 1 inch (2.5 cm) in size

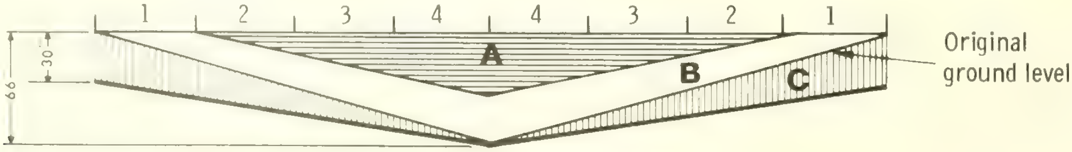

Figure 1.--Cross-section of experimental site depicting cut in native soil (C), processed oil shale fill (B and C), and native soil fill (A).

was spread to a depth of 6 inches (15.2 cm) over half of the area covered by processed shale and the graveled area then covered with native soil to a depth of 1 foot (30.5 cm). Native soil was spread over the other half of the processed shale to a depth of 18 inches (0.46 m).

On December 14, 1976, seeds of 24 chenopod shrubs were planted in single rows and replicated four times for comparison with container-grown plants of the same species. Plots were 5 feet (1.5 m) wide and 10 feet (3 m) long. Each plot contained one row of fall-planted seed and one row of container-grown plants. Rows were spaced 30 inches (0.76 m) apart, and container-grown plants within rows were also spaced 30 inches apart. This allowed four times as much space per plant as in the first study.

RESULTS

Site 1

Table 1 shows percent survival of seven chenopods in 1982, 6 years following the first planting. Highest percent survival was exhibited by _Atriplex obovata_ Moq., _Atriplex bonnevillensis_ C.A. Hanson, and _Kochia prostrata_, with _Atriplex tridentata_ Kuntze not far behind. _Kochia prostrata_ var. _villosissima_ was not planted in all replications due to shortage of plants and is not shown in the table, but it was planted in all treatments. This species showed 100 percent survival where planted, but fewer plants were involved than for the other species.

Results at the end of the second growing season (1977) showed that supplementary water had the most beneficial effect on the plots of processed shale where no soil covering was applied, and that the advantage of watering tended to disappear with increasing depth of topsoil over shale (Frischknecht and Ferguson 1979). Although plants received no supplementary water after 1977, benefits of the early irrigations were evident to some degree in 1982 (table 1).

From the standpoint of reproduction, _K. prostrata_ (both varieties) and _Camphorosma monspeliacum_ L. were by far the most prolific. Seeds of these species are small, and whatever amount of soil covering was required for germination and establishment was provided by conditions associated with overwintering. Some _Kochia_ and _Camphorosma_ plants became established outside the exclosure in bare spaces in the native vegetation, probably from seeds collected by small rodents. A few new plants of all three _Atriplex_ species established from seed, but the number was small compared to _Kochia_ and _Camphorosma_.

Seeds of the three introduced species (_K. prostrata_, _C. monspeliacum_, and _Ceratoides papposa_) were brought to this country through efforts of Dr. Wesley Keller (retired), formerly with the Agricultural Research Service (ARS). The _A. bonnevillensis_ used in the study came from seeds collected from plants growing on a playa at the Desert Experimental Range in southwestern Utah. _Atriplex tridentata_ came from seeds collected in Rush Valley, Utah, and _A. obovata_ from seeds collected near the Hatch Trading Post in southeastern Utah. _Ceratoides lanata_ (Pursh) J.T. Howell came from seeds collected at two places; near the Desert Experimental Range, and near Duchesne in Utah's Uinta Basin. Few or no differences were observed in survival of plants from these two origins.

In addition to the species shown in table 1, a limited number of container-grown plants was obtained from Dr. Howard Stutz, geneticist, Brigham Young University, for use in the 1976 study at Sand Wash. These included 16 plants each of nine species or accessions of _Atriplex_ as follows: _Atriplex canescens_ from Jericho and Emery in Utah, and White Sands, N. Mex.; _Atriplex aptera_ from Bridger, Mont., and Edgar, Mont.; _A. obovata_ from San Ysidro, N. Mex.,; _A._ lentiformis (Torr.) Wats. from St. George, Utah; _A. polycarpa_ (Torr.) Wats. from Sonoma, N. Mex.; and an undescribed taxon from San Roberta, Mexico. The latter three species had no survivors in 1982; most of the plants died during the first or second winter. The _A. canescens_ from White Sands survived through the first three growing seasons but died in the third winter. Accessions of _A. aptera_, both accessions of _A. canescens_ from Utah, and the _A. obovata_ from New Mexico had some surviving plants in 1982.

Results of this study indicate that processed shale should be covered with at least 1 foot of topsoil for best establishment and survival of plants.

Table 1.--Percent survival of seven chenopods in 1982, six years after planting, Site 1.

Species	Irrigated 1976-77 Soil depth over shale, ft None	0-1	1-2	2-3	Mean	Nonirrigated Soil depth over shale, ft None	0-1	1-2	2-3	Mean
Atriplex bonnevillensis	56	81	100	88	81.2	69	81	81	81	78.0
A. obovata	69	75	88	100	83.0	62	94	89	94	84.8
A. tridentata	50	62	88	50	62.5	69	88	50	62	67.2
Camphorosma monspeliacum	38	62	44	56	50.0	19	81	56	62	54.5
Ceratoides lanata	0	44	50	38	33.0	0	12	75	38	31.2
C. papposa	6	62	81	75	56.0	0	31	44	75	37.5
Kochia prostrata	88	81	69	81	80.0	50	69	75	94	72.0
Mean	43.8	66.7	74.3	69.7	63.6	38.4	65.4	67.1	72.3	60.8

Site 2

The second study at Sand Wash involved comparing the growth and survival of container-grown plants set out in the spring with plants established by direct seeding the previous fall. Sparse germination resulted from fall-planted seeds because of drought in the winter of 1976-77. Although 18 of the species showed a little germination in May, only 14 species had plants surviving by fall. All seed rows were replanted in the fall of 1977 to the same species, and excellent germination resulted in the spring of 1978. In fact, it appeared that many ungerminated seeds from the original planting germinated in the second year. Some of the ungerminated first-year seed had been scraped just outside the original rows in making the second planting.

Some thinning was done in the rows established from seeds so that these plants would have somewhat comparable room for growth as the transplants from containers.

Percent survival and average height of the container-grown plants are shown in table 2. Survival is not shown for plants from seeds because the numbers of plants after thinning were not equal. Also, additional germination occurred after the thinning. Generally speaking, the number of surviving plants from seed was equal to or greater than the number of survivors from container-grown plants. In some instances, plants from containers were larger in 1982 than those established from seed, but most were comparable in size.
Superior survival of container-grown plants 5 years following planting was exhibited by the two ecotypes of *K. prostrata*. Reproduction of these plants was superior to any other species. *Kochia prostrata* var. *villosissima* was more prolific than the other ecotype, which is greener in color because of less pubescence. Most plots of *Atriplex* were invaded to some extent by new plants of *Kochia*.

Table 2.--Percent survival and average height of 24 chenopods in 1982, five years after establishment by transplanting, Site 2.

Species	Origin	Survival (percent)	Height (inches)	Height (cm)
Atriplex aptera	Scenic, S. Dak.	81	12	30
A. aptera	Circle, Mont.	6	14	36
A. aptera	Drumheller, Alberta	0	--	--
A. aptera	Crawford, Neb.	50	19	48
A. canescens	Jericho, Utah	31	42	107
A. canescens	White Sands, N. Mex.	12	24	61
A. canescens	Thermopolis, Wyo.	56	9	23
A. canescens	Eureka, Nev.	9	13	33
A. canescens	Uinta Basin, Utah	84	26	66
A. lahontanensis[1]	Battle Mountain, Nev.	44	11	28
A. navajoensis	Navajo Bridge, Ariz.	12	11	28
A. gardneri	Worland, Wyo.	94	8	20
A. tridentata	Uinta Basin, Utah	75	16	41
A. confertifolia	Rush Valley, Utah	[2]--	--	--
Atca x *A. idahoensis*	Grandview, Idaho	94	13	33
Atca x *A. cuneata*	Hanksville, Utah	88	16	411
Atca x *A. tridentata*[1]	Skull Valley, Utah	44	10	25
Atca x *A. nevadensis*[1]	Marble Mine, Nev.	75	11	28
Ceratoides lanata	Sanpete County, Utah	38	13	33
Grayia spinosa	Uinta Basin, Utah	56	12	30
Camphorosma monspeliacum	Soviet Union	75	9	23
Kochia prostrata	Soviet Union	94	16	41
K. prostrata var. *villosissima*	Soviet Union	94	17	43
Sarcobatus vermiculatus	Uinta Basin, Utah	75	15	38

[1]Undescribed taxa, provided by Dr. Howard Stutz.
[2]Container-grown plants not available.

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SEEDING SHRUBS WITH HERBS ON A SEMIARID MINE SITE WITH AND WITHOUT TOPSOIL

Stephen B. Monsen and Bland Z. Richardson

ABSTRACT: The establishment and survival of shrubs seeded in a mixture with herbs on topsoil and mine waste materials were compared in north-central Nevada. Topsoil provided an improved seedbed for all species planted. Fourwing saltbush, rubber rabbitbrush, and forage kochia all established and grew well under both topsoil and control treatments. Shadscale saltbush did not persist on either treatment. Wyoming big sagebrush established and grew satisfactorily only on the topsoil treatment. A higher percentage of fourwing saltbush seeds germinated and became established than any other seeded shrub. Seeding shrub and herb seeds together did not appear to result in seedling losses due to plant competition. Shrub seedlings were better adapted to the barren treatment than the herbs. Cultipack seeding was a successful method of planting seeds of different size and shape.

INTRODUCTION

Mining has been an important industry in north-central Nevada since settlement. Revegetation of most mined areas has not been attempted because of costs and low productivity, but restoration of mined areas is often necessary to reduce further degradation and limit impacts to associated soils, watershed, and wildlife resources.

Mining in north-central Nevada occurs over an extensive area where the average annual precipitation is less than 16 inches (40 cm). Infertile soils are also characteristic. These conditions significantly reduce the success of revegetation by limiting the establishment of seedlings and the persistence of older plants. Nicholas and McGinnies (1982) determined that applying topsoil to mine disturbances increased herbage and root production of seeded plants. In addition, Cundell (1977) found that fertilizer and inoculation of the rhizosphere with heterotrophic nitrogen-fixing bacteria improved reclamation of mined sites.

Few native or introduced species are adapted to semiarid mine disturbances. To date, most revegetation efforts have relied upon the use of grasses that have been developed for wildland plantings (Lawrence and Troelsen 1964; Gomm 1974; Wilson and Smoliak 1977; Lawrence 1981). Although these plants are useful and possess desirable characteristics, not all mined disturbances can be satisfactorily restored with grasses. Even the most tolerant grass cultivars may succumb to adverse conditions (Currie and White 1982).

Relatively few native shrubs or broadleaf herbs have been thoroughly evaluated for revegetating mined areas. However, Ferguson and Frischknecht (1981) identified various shrubs and herbs that are adapted to semiarid sites within the Intermountain region and can enhance forage yields and ground cover. Plummer and others (1968) reported that seeds of big sagebrush (Artemisia tridentata Nutt.), rubber rabbitbrush (Chrysothamnus nauseosus [Pallas] Britt.), fourwing saltbush (Atriplex canescens [Pursh] Nutt.), and common winterfat (Ceratoides lanata [Pursh] J. T. Howell) germinate readily and developed competitive seedlings in range and wildlife plantings. Stevens and others (1981) reported that forage kochia (Kochia prostrata [L.] Schrad.), a recent introduction from the U.S.S.R., also performs well in range seedings. DePuit and Coenenberg (1979), Aldon (1981), and Holechek and others (1981) found that fourwing saltbush is particularly well adapted to mixed plantings on mine spoils.

Direct seeding of shrubs has not always been a dependable method of plant establishment under semiarid conditions (Van Epps and McKell 1980). Erratic seed germination and competition between developing shrub and grass seedlings has limited shrub establishment (Howard and others 1979; Aldon and Pase 1981).

This study was initiated to determine the compatibility of various woody shrubs and herbs seeded on an abandoned mined site in north-central Nevada. The effects of topsoiling to enhance seedling establishment and plant growth were also evaluated.

METHODS

Plantings were established on the Beacon Pit Mine, located about 12 miles (20 km) southeast of Battle Mountain, Lander County, Nev. Approximately 100,000 tons (90 719 metric tons) of barite ore had been mined from the site. The ore was removed from

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an open pit approximately 600 feet (183 m) long, 250 feet (76 m) wide, and 60 feet (18 m) deep. The waste rock and overburden material have been sidecast near the pit. Prior to planting, the waste dump was leveled. A portion of the dump was topsoiled to a depth of approximately 5 inches (12 cm). An adjacent portion of the dump was not topsoiled, but left as the control treatment.

Topsoil was taken from an area adjacent to the mine. The native collection site supported a dense stand of Wyoming big sagebrush (Artemisia tridentata Nutt. ssp. wyomingensis Beetle and Young) with a scattered understory of bunchgrass and cheatgrass brome (Bromus tectorum L.). Rubber rabbitbrush was intermixed with the Wyoming big sagebrush, but occurred as a minor element in the shrub-dominated community. However, rubber rabbitbrush had spread onto abandoned mine disturbances along with halogeton (Halogeton glomeratus C.A. Ney) and cheatgrass brome. Scattered stands of shadscale saltbush (Atriplex confertifolia [Torr. & Frem.] Wats.), Nevada ephedra (Ephedra nevadensis Wats.), and common winterfat also occurred near the mine.

The study sites were prepared and planted December 3 to 6, 1978. Following application of the topsoil, both the control and topsoil areas were fertilized, harrowed, and seeded. Fertilizer was applied at a rate of 50 pounds per acre (56 kg/ha) using a commercial fertilizer with nitrogen, phosphorus, and potassium in a ratio of 16-16-16.

A seed mixture consisting of five species of grass, four broadleaf herbs, and five shrubs was planted on both the topsoil and control sites using a Brillion cultipack seeder. Vallentine (1980) describes the features of this seeder. Seeds of all species were mixed and seeded together. The species planted and seeding rates are listed in table 1.

In June 1979, the new plantings were fenced to prevent rabbit depredation. A precipitation gage was established at the study on February 2, 1979. Moisture received was recorded on a monthly basis throughout the duration of the study.

Following planting, five permanent transects, each 25 feet (7.6 m) by 15 feet (4.6 m) were randomly established on both the topsoil and control sites. Each shrub rooted in a transect was recorded by species. Growth measurements were taken yearly beginning in 1980. These measurements included maximum plant height, crown spread, and annual herbage production (green weight).

Density and annual herbage production of the grasses and broadleaf herbs were measured by randomly establishing 10 subplots, each 2.28 ft^2 (1 m^2), in both the topsoil and control plots. The number of grass, forb, and shrub seedlings occurring in the subplots were counted and recorded in 1980 and 1982. The subplots were also used to estimate ground cover of each species, litter, and bare soil.

Table 1.--Seed characteristics and species seeded at the Beacon Pit Mine, Nev., 1979.

Species seeded	Seed origin	Bulk rate planted lb/acre	Seed features: Germination percent	Purity percent	Number PLS[1]/lb	Number PLS/acre
GRASSES						
Agropyron cristatum 'Nordan'	Commercial	3	90	94	253,800	761,400
Agropyron riparium	Commercial	3	90	95	135,945	407,835
Elymus cinereus	Commercial	1	45	60	33,480	33,480
Oryzopsis hymenoides	Aberdeen PMC, Idaho	2	96	99	133,056	266,112
Psathyrostachys juncea	Commercial	2	90	92	138,276	276,552
BROADLEAF HERBS						
Linum lewisii	Sanpete Co., Utah	0.3	80	99	267,519	88,281
Medicago sativa	Commercial	2	87	99	181,150	362,301
Melilotus officinalis	Commercial	2	77	99	162,230	324,460
Sanguisorba minor	Commercial	2	95	99	52,093	104,186
SHRUBS						
Artemisia tridentata wyomingensis	Carey, Idaho	2.3	80	15	300,000	699,000
Atriplex canescens	Lincoln Co., Nevada	4	56	91	22,340	89,361
Atriplex confertifolia	Battle Mt., Nevada	0.3	10	86	7,287	2,404
Chrysothamnus nauseosus	Ada Co., Idaho	2	[2]75	21	25,600	51,201
Kochia prostrata 'Immigrant'	Breeder seed	2	[2]66	65	154,847	309,695

[1] PLS = pure live seeds.
[2] Estimated value not confirmed by germination tests.

Factorial analyses of variance were used to compare the two treatments. Annual species densities were compared using a one-way analysis of variance. The results were considered to be significantly different at $P \leq 0.05$.

RESULTS AND DISCUSSION

Precipitation

During the study period 1979 to 1982, annual precipitation varied from 5.45 inches (13.8 cm) in 1982 to 11.09 inches (28.1 cm) in 1980 (table 2). During the season of plant establishment (1979), the site received 6.55 inches (16.6 cm) of moisture. The maximum moisture during any year occurred in the spring and summer months (March to June). Amounts of 7.6 inches (19.3 cm) and 6.18 inches (15.7 cm) were recorded during this seasonal period in 1980 and 1982, respectively. Although the annual amounts are quite low, the bulk of precipitation came during the early part of the growing season. Apparently sufficient moisture was received to initiate and sustain seed germination and seedling establishment.

Plant Establishment and Development

Grasses and broadleaf herbs.--Grass seeds of Fairway wheatgrass 'Nordan' (*Agropyron cristatum* [L.] Gaertn.), riparian wheatgrass (*Agropyron riparium* Scribn. & Sm.), Indian ricegrass (*Oryzopsis hymenoides* [R.&S.] Ricker in Piper), and Russian wildrye (*Psathyrostachys juncea* [Fischer] Nevski) germinated and seedlings emerged within the topsoil treatment in 1979. Although seedling counts were not recorded in 1979, grass seedlings were also observed in the control site in 1979. The topsoil provided a better seedbed for grasses than the soil of the control site. The percent ground cover of seeded grasses was significantly greater on the topsoil area ($P \leq .05$) for all years sampled (table 3).

The seeded grasses failed to provide measurable cover in the topsoil site until 1980 (table 3). Plant numbers remained unchanged, yet plant cover increased from 6 percent in 1981 to 15 percent in 1982.

Fairway wheatgrass was the only seeded grass to appear in the control treatment. By 1982, 4 years after seeding, this species provided only 1 percent

Table 2.--Seasonal and annual precipitation, Beacon Pit Mine, 1979 to 1982.

Season	Moisture received			
	1978-79	1979-80	1980-81	1981-82
	- - - Inches - - -			
October to February (winter)	2.07	3.09	1.72	2.00
March to June (spring-summer)	2.57	7.60	6.18	2.82
July to September (summer-fall)	1.91	.40	0.0	.63
Total (water year)	6.55	11.09	7.90	5.45

Table 3.--Mean annual ground cover for the topsoil and control treatments.

Species	Topsoil			Control		
	1980	1981	1982	1980	1981	1982
	- - - Percent - - -					
Seeded grasses	2	6	15	[1]T	1	1
Native grasses - perennials	0	T	1	0	0	0
Annual grasses	7	8	3	3	2	2
Native broadleaf forbs	0	T	0	1	0	T
Seeded broadleaf forbs	0	0	0	0	0	0
Seeded shrubs[2,3]						
Atriplex canescens	3	10	16	T	1	2
Atriplex confertifolia	0	0	0	0	0	0
Artemisia tridentata wyomingensis	1	3	5	0	0	0
Chrysothamnus nauseosus	2	6	9	1	1	2
Kochia prostrata	T	1	2	0	T	1
Total live cover	15	34	51	5	5	8
Litter	6	5	14	1	T	1
Bare ground	79	61	35	94	95	91

[1]T = trace amounts recorded.
[2]Shrub ground cover significantly different between the two treatments (P = 0.002).
[3]Shrub ground cover significantly different among species (P = 0.0426).

cover. Only a few new grass seedlings have been recorded in the control treatment since the site was planted.

Virtually no seeded broadleaf herbs established in either the topsoil or control areas. Prior to fencing in June 1979 rabbits severely grazed almost all young seedlings. The impact these animals had upon the survival of the seeded herbs is not fully known. Rabbits were observed to selectively graze the broadleaf seedlings.

Neither the topsoil or control treatments became infested with weeds. Cheatgrass brome provided 8 percent ground cover on the topsoil treatment in 1980, but only 3 percent in 1982 (table 3). On the control treatment, cheatgrass brome cover was 3 percent in 1980. This remained about the same in 1981 and 1982. The topsoil did not introduce or spread weeds. Although halogeton occurs along roadways and other disturbances, it did not invade either treatment site. The only native broadleaf forbs to appear in either study area were clasping pepperweed (Lepidium perfoliatum L.) and a few annual mustards (Sysymbrium spp.). Few native herbs are encountered adjacent to the mined site. Consequently, natural invasion has been seriously limited.

Seeded shrubs.--Numerous shrub seedlings established on the topsoil treatment (table 4). Significantly fewer plants ($P \leq 0.05$) were found in the control treatment for each shrub species planted and for each of the 3 years sampled.

Over 9,000 fourwing saltbush seedlings were recorded per acre (22 000/ha) in the topsoil treatment in the spring of 1980 (table 4). The number diminished to about 5,000 plants per acre (12 000/ha) in 1981 and 4,000 plants per acre (10 000/ha) in 1982. A total of 142 plants per acre (347/ha) were recorded on the control treatment in 1980. The number diminished to 117 per acre (286/ha) in 1982. Although significantly fewer ($P \leq 0.05$) fourwing saltbush seedlings were recorded in the control treatment, 82 percent of the plants counted in 1980 survived until 1982. During the same period, only 45 percent survival was recorded for this species in the topsoil treatment. Some plant mortality in the topsoil is to be expected due to the large number of seedlings established. As the community stabilizes and the plants reach maturity, some natural thinning will occur.

A significantly higher percentage of fourwing saltbush seedlings established on the topsoil treatment than any other seeded shrub. Approximately 10 percent of all viable fourwing seeds planted developed into established seedlings in 1980 (table 4). This figure dropped to 4.67 percent by 1982. This is a higher return than reported by previous investigators for shrub species planted on mine sites (Luke and Monsen, this proceedings), and is much higher than reported for antelope bitterbrush (Purshia tridentata [Pursh] D.C.) plantings in southwestern Idaho rangelands (Monsen and Shaw 1983). Only 0.16 percent of all viable fourwing saltbush seeds appeared as seedlings in the control treatment in 1980 (table 4). By 1982 the figure diminished slightly to 0.13 percent. Plummer (1977) and McArthur and others (1983) recognized differences among ecotypes of fourwing saltbush and suggested that considerable improvement in seedling vigor and other traits could be attained through the use of select types. The selection seeded in this study demonstrates excellent seedling vigor and seed germination potential.

In both the topsoil and control treatments, fourwing saltbush required about 4 years to become fully established, however, nearly all seeds germinated the first year. No recruitment of new seedlings was recorded in subsequent years.

Table 4.--Number of shrub seedlings and percent viable seeds to establish on the topsoil and control sites, Beacon Pit Mine, Nev.[1]

Species seeded	No. seeds planted PLS[2]/acre	Plant counts: Topsoil 1980	Topsoil 1981	Topsoil 1982	Control 1980	Control 1981	Control 1982	Percentage of seeds to establish: Topsoil 1980	Topsoil 1981	Topsoil 1982	Control 1980	Control 1981	Control 1982
		Number/acre						Percent					
Atriplex canescens	89,361	9,225	4,935	4,170	142	117	117	10.32	5.52	4.67	0.16	0.13	0.13
Atriplex confertifolia	2,404	40	14	0	0	0	0	.83	.58	0	0	0	0
Artemisia tridentata wyomingensis	699,000	1,555	1,567	1,569	0	0	0	.22	.22	.22	0	0	0
Chrysothamnus nauseosus	51,201	1,759	2,314	2,577	351	388	421	3.43	4.52	5.03	.68	.76	.82
Kochia prostrata	309,695	262	280	280	46	46	46	.08	.09	.09	.01	.01	.01
TOTAL		12,821	9,110	8,596	539	551	584						

[1]Significant difference ($P = 0.001$) between treatments, between species, and treatment species interaction.
[2]PLS = pure live seed.

Approximately 47 percent of all seedlings recorded on the topsoil site died between 1980 and 1981. By 1982, an additional 8 percent were lost. Thus, approximately 55 percent of the seedlings that emerged and persisted the first year died in the following 3 years. Losses now appear to be stabilizing; existing plants are large and healthy. More than 80 percent of the fourwing saltbush seedlings recorded on the control site in 1980 persisted as established plants in 1982.

The majority of fourwing saltbush plants to establish on the topsoil site grew rapidly and attained a mature stature in 4 years. Some fourwing saltbush seedlings and young plants grew erratically, but most grew faster than other seeded shrubs (fig. 1). Nearly 70 percent of all plants surviving in 1982 were taller than 10 inches (26 cm); 45 percent were taller than 20 inches (50 cm). Competition among seeded species appears to have suppressed the growth of some fourwing saltbush seedlings, but by 1982 only 8 percent of all existing plants were less than 5 inches (13 cm) in height.

Significantly fewer ($P \leq 0.05$) Wyoming big sagebrush seedlings established within the topsoil treatment than did fourwing saltbush (table 4). No Wyoming big sagebrush plants established on the control treatment. Most of the Wyoming big sagebrush seedlings that appeared on the topsoil site germinated the first year, however, establishment continued for perhaps 2 years. Nearly all plants counted in 1980 survived until 1982. The young plants grew rapidly, and did not appear to be suppressed by other shrubs. By 1982, few individuals were as large as the fourwing saltbush plants, yet most were over 11 inches (30 cm) tall (fig. 2). Plants are very uniform in height, yield, and vigor.

Only 0.22 percent of all viable Wyoming big sagebrush seeds planted into the topsoil area developed into established plants. The low return apparently is related to characteristics of the seedbed. Few seedlings emerged but those that appeared survived.

A number of rubber rabbitbrush seedlings established on the topsoil site by 1980 (table 4). The topsoil significantly ($P \leq 0.05$) increased the initial establishment of rubber rabbitbrush seedlings. Approximately four times more plants established initially in the topsoil area than in the control area.

The number of rubber rabbitbrush plants has increased annually from 1980-1982 on both planting sites (table 4). This apparently resulted from seeds being blown into the study areas from mature bushes of the surrounding plant community. Since 1980, rabbitbrush plant numbers have increased about 34 percent on the topsoil treatment, and over 73 percent within the control planting. Recruitment of new plants in the topsoil treatment continued even through approximately 13 percent of all 1- and 2-year-old plants die every year. Seedling mortality has not been detected in the control area. Approximately 3.44 percent of all viable rubber rabbitbrush seeds initially planted became established in the topsoil treatment (table 4). Only 0.68 percent establishment occurred in the control planting.

Figure 1.--Three-year-old plants of fourwing saltbush, rubber rabbitbrush, and 'Immigrant' forage kochia growing on the topsoil plot, Beacon Pit Mine, Nev.

Seedlings of 'Immigrant', a cultivar of forage kochia, established on both treatments (table 4); but the number of plants was significantly greater ($P \leq 0.05$) on the topsoil site. A low return of planted seeds was recorded for this species in both the topsoil (0.08 percent) and control (0.01 percent) treatments (table 4). All seedlings recorded in 1980 for both treatments survived through 1982, and were of similar size.

Seeds of 'Immigrant' forage kochia germinated the first spring after planting in both treatments; no new plants were recorded in subsequent years. Young seedlings developed slowly, yet after 2 years of growth the plants attained sufficient stature to become highly competitive.

Plants of surviving shrub species grew rapidly in the topsoil treatment. The total ground cover for all shrubs was 6 percent in 1980 (table 3). This increased to 32 percent by 1982. Shrubs that established in the control treatment also grew rapidly, yet the limited number of established plants furnish significantly lower total ground cover. Since 1980, the cover provided by shrubs in the topsoil treatment was double the figure recorded for all herbaceous plants (table 3).

Fourwing saltbush furnished the greatest cover of all seeded species for all years. The accelerated growth of fourwing saltbush, Wyoming big sagebrush, rubber rabbitbrush, and forage kochia is an important trait in providing an initial cover to disturbed sites (fig. 2).

Herbage Production

Topsoil was beneficial to the initial growth and herbage yield of the seeded shrubs and herbs; however, individual species responded differently (table 5). After 4 years, individual plants of fourwing saltbush, rubber rabbitbrush, and 'Immigrant' forage kochia were equally vigorous and nearly the same size on the control and topsoil sites.

Table 5.--Annual herbage production for topsoil and control treatments, Beacon Pit Mine, Nev.

	Topsoil		Control	
Species	1981	1982	1981	1982
	- - - - -	lb/acre	- - - - -	
Seeded grass	584	498	79	79
Annual grass	5	12	12	12
Native forbs	6	0	6	0
Seeded forbs	0	0	0	0
Seeded shrubs[1]				
Atriplex canescens	451	1357	40	86
Artemisia tridentata wyomingensis	122	295	0	0
Chrysothamnus nauseosus	150	594	26	248
Kochia prostrata	64	34	13	75
Atriplex confertifolia	2	0	0	0
TOTAL	1384	2790	184	443

[1]Shrub production significantly different between the two treatments ($P = 0.0401$).

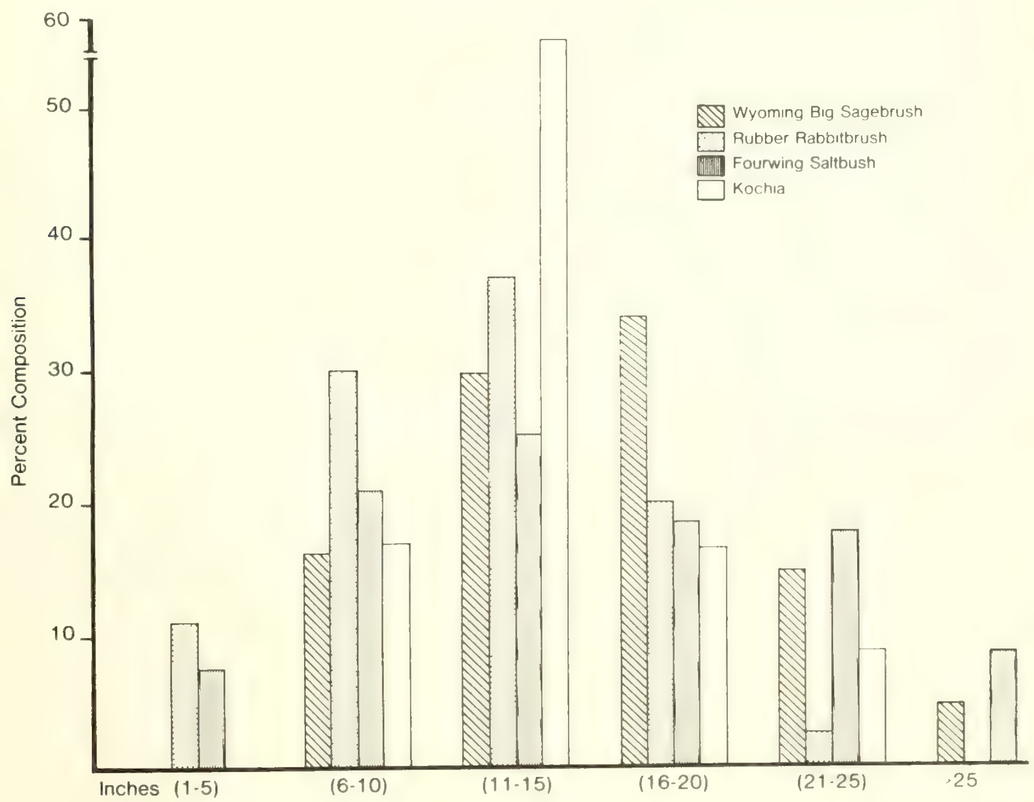

Figure 2.--Percent composition of plants by height class for 4-year-old shrubs growing on top soil.

A greater number of fourwing saltbush, Wyoming big sagebrush, and rubber rabbitbrush plants established on the topsoil site, which influenced the total herbage produced. With the exception of 'Immigrant' forage kochia, the topsoil treatment resulted in a significantly greater ($P \leq 0.05$) amount of herbage produced than the control site (table 5). Differences were significant for 1981 and 1982. Established plants of fourwing saltbush and rubber rabbitbrush were quite vigorous in both the topsoil and control treatments, and produced a large volume of annual growth.

About equal numbers of 'Immigrant' forage kochia plants established on each treatment site. By 1982, plants in the control plot produced nearly twice the amount of annual herbage as those on the topsoil site. This shrub appeared well adapted to the harsh soil conditions created by mining.

Shrubs were much more productive in both treatments than the seeded herbs. Although the topsoil significantly benefited ($P \leq 0.05$) the production of herbs, total production of the understory species was considerably less than the combined yield of the shrubs. Forage produced by shrubs was greater in all years sampled than grass yield. This is an important aspect to consider in providing immediate ground cover and forage production.

Shrub-Herb Mixed Seeding

Effects of mixing and seeding shrubs with grasses and broadleaf herbs were not fully determined in this study. Clarke and DePuit (1981), and DePuit and others (1980) found that when seeded together competition from grass seedlings can be detrimental to slower developing shrubs. Although topsoil increased grass density at the Beacon Pit Mine, the ground cover of the seeded grasses remained less than 15 percent. Apparently this amount of herbaceous cover was not detrimental to shrub seedling establishment and survival. Shrubs were much better adapted to the control treatment than the seeded herbs. Very few herbaceous plants became established on the control site to compete with the shrubs. Planting shrubs on semiarid mine wastes is a viable means of establishing plant cover, particularly on sites where herbs are difficult to establish.

Cultipack Seeding

The Brillion cultipack seeder was effective in seeding the shrub-herb mixture. The machine adequately planted the larger seeds of fourwing saltbush and rubber rabbitbrush. The long brittle achenes of rubber rabbitbrush were not damaged by the seeder. The machine was also capable of seeding the small seeds and chaff or trashy material of Wyoming big sagebrush. Small seeds of Wyoming big sagebrush and 'Immigrant' forage kochia were uniformly dispersed. A low return of the small-seeded species suggests that these seeds were not correctly planted, but shrub density of the small-seeded plants was acceptable.

CONCLUSIONS

Seeded grasses were not well adapted to the mine wastes. Few grass seedlings germinated in the control treatment. Topsoil significantly improved the seedbed condition for grasses and improved herbage production. Seeded broadleaf herbs failed to establish in either treatment, but rabbit grazing may have accounted for the death of all seedlings.

The seeded shrubs of fourwing saltbush, rubber rabbitbrush, and 'Immigrant' forage kochia all are well adapted to both the topsoil and control treatments. Topsoil significantly improved the seedbed condition for all seeded shrubs, yet plants also established in the control area. The collection of fourwing saltbush from Panaca, Lincoln Co., Nev. that was planted at the mine site demonstrated excellent seedling survival and growth. A considerably higher return of planted seeds occurred with this species than any other seeded shrub. This selection appears promising for mine reclamation in semiarid regions.

Rubber rabbitbrush is adapted to the mine disturbances, but did not establish as well as fourwing saltbush from direct seeding. However, the plant spread quickly from natural seeding, and was able to establish on the rough, barren surfaces throughout the control and topsoil sites.

The cultivar of forage kochia, 'Immigrant', appears well suited to mine sites. Only scattered plants established in both treatments, but low seed viability may have accounted for the variable stand. Established plants grew very well in both treatments, and natural spread appears highly possible.

Seedlings of Wyoming big sagebrush established only on the topsoil site. This may be due to the seedbed conditions of the control site or the lack of adaptability of the sage to the mine wastes.

All seeded species of shrubs, except shadscale saltbush, grew quickly and were compatible with seeded herbs. Shrubs were better adapted to the mine disturbances than the herbs, and can be used to provide an immediate, yet effective cover.

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ATRIPLEX SUCKLEYI (Torrey) Rydb.: A NATIVE ANNUAL PLANT FOR REVEGETATING BENTONITE MINE SPOILS

Marguerite E. Voorhees, Daniel W. Uresk, and Richard M. Hansen

ABSTRACT: Rillscale (Atriplex suckleyi [Torrey] Rydb.) is a plant that may have potential for revegetating bentonite mine spoils following spoil modifications. Sawdust and gypsum amendments were effective for improving spoils as a plant growth medium when applied in the fall. Spring applications of sawdust were less effective and spring applications of gypsum were ineffective. Fertilizers (NPK) generally had no effect on plant growth.

INTRODUCTION

In the selection of plant species for revegetation of mined lands, several factors must be considered, including climate, soil or spoil characteristics, and postreclamation land use plans. On sites harsh to plant growth, it may be necessary to use species representing lower successional stages.

Bentonite mine spoils of the northern Great Plains represent one example of harsh sites that pose several problems for revegetation. Spoils are typically saline-sodic, with an electrical conductivity of more than 9 mmhos/cm and a sodium adsorption ratio of 20-56 (Bjugstad and others 1981; Yamamoto and Uresk 1981). High percentages of shrink-swell clays dominate the spoils and can result in damage to root systems. Spoils may also be low in nitrogen, although levels of other nutrients appear adequate. Annual rainfall ranges from 9 to 24 inches (25 to 60 cm). Moisture is deficient throughout most of the year (Thornburg and Fuchs 1978); up to 75 percent of annual precipitation is received from April to September. Topsoil above bentonitic shales is characteristically shallow and poorly developed.

Efforts to establish vegetation on bentonite mine spoils have generally failed. These efforts have included the use of grasses, forbs, shrubs, and trees, with many of these species being considered tolerant to salt. Yamamoto and Uresk (1981) conducted a greenhouse study on bentonite mine spoil and tested eight species of drought- and alkaline-tolerant trees, forbs, and shrubs to determine if certain spoil amendments might improve survival rates. They found that sawdust was especially effective for increasing survival of fourwing saltbush (Atriplex canescens [Pursh] Nutt.), rubber rabbitbrush (Chrysothamnus nauseosus [Pall.] Britt.), big sagebrush (Artemisia tridentata Nutt.), winterfat (Ceratoides lanata [Pursh] Moq.), Russian-olive (Elaeagnus angustifolia L.), and yarrow (Achillea lanulosa Nutt.).

Sieg and others (1983), in a study of biota of bentonite mine spoils in Montana, found a spreading annual chenopod, Atriplex suckleyi (Torrey) Rydb., commonly called rillscale, to be the dominant, native invader. Rillscale is limited in range to the northern Great Plains. It has been noted for its occurrence on clayey, saline lands "where no other plant species seem to grow" (Frankton and Bassett 1970). The plant may grow to 1 foot (39 cm) in height and has an apparent plastic morphology on bentonite mine spoils. As a member of the genus Atriplex, highly valued among rangemen, rillscale may be useful as a forage plant.

In view of its success on bentonite mine spoils, rillscale was selected as an appropriate species for use as an indicator of the value of amendments for improving bentonite mine spoils as plant growth media. Also of interest was the potential of rillscale for use in revegetation of bentonite mine spoils. By acting as a pioneering species on spoils, rillscale may have important stabilizing effects. Also, it may modify spoils in a way that would eventually prove conducive to the establishment, survival, and growth of plant species representing higher successional stages.

The objectives of this study were to evaluate the effects of (1) spoil amendments (gypsum, sawdust, and fertilizer) on production, height, and cover of rillscale on bentonite mine spoils; (2) season of amendment on production, height, and cover of rillscale on bentonite mine spoils; (3) seeding on the density of rillscale on the amended spoil; and (4) season of seeding on the density of rillscale on the amended spoils.

The study area was just west of the central Black Hills on the Mowry Shale formation, approximately one mile northwest of Upton, Wyo. Sites on the property had been mined at various times for more than 30 years,

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but not later than 1968.[1] Elevation was approximately 4,230 feet (1 290 m). Average annual precipitation was about 14 inches (35 cm) (NOAA 1981). Vegetation is characteristically big sagebrush-grass interspersed with stands of ponderosa pine (Pinus ponderosa Laws). The area provides forage for many species of wildlife, including antelope (Antilocapra americana americana [Ord]) and mule deer (Odocoileus hemionus hemionus [Rafinesque]), as well as for livestock.

METHODS

The experimental design was a 2^3 factorial arrangement, with each of three spoils amendments at two levels, one level the absence of the amendment and the other the presence of the amendment. The three amendments were: (1) gypsum, applied at the rate of 14 tons per acre (31 metric tons/ha); (2) fertilizer, added at the rate of 100 pounds nitrogen per acre (113 kg/ha), 18 pounds phosphorus per acre (20 kg/ha) and 45 pounds potassium per acre (50 kg/ha); and (3) sawdust, added at the ratio of one part sawdust to two parts spoil (by volume), with nitrogen corresponding to 0.6 percent of sawdust (by weight).

The study site was rototilled to a depth of approximately 2 inches (5 cm).

Gypsum and sawdust amendments were manually incorporated into tilled spoil, while fertilizer amendments were applied on the surface. Eight combinations of the three amendments were replicated six times, each replication representing one randomized block, to give a total of 48 plots. Three of these replications were seeded and three were left unseeded, for comparison of seeded and volunteer growth. One set of 48 plots was tilled, amended, and seeded in September 1981; another set of 48 plots was tilled, amended, and seeded in April 1982.

Seeds were obtained from sites along the Montana-Wyoming border during late summer 1980. Approximately 20 live seeds per square inch (3 seeds/cm^2) were planted in each seeded plot. The weight of seed needed to achieve this density was calculated from total percentage germination and seed density determinations made within 6 weeks before planting. Seed was broadcast on the surface and lightly covered with spoil.

Maximum plant height and stem density were measured and recorded on five 4- X 4-inch (10-cm^2) quadrats in each plot beginning in mid-May and continuing at 3-week intervals throughout the 1982 growing season. The quadrats were located at 12-inch (30-cm) intervals on a transect running the length of each plot. Total canopy cover was visually estimated for each plot, using six cover classes (Daubenmire 1959). Aboveground production for each plot was harvested from the entire plot at the end of the 1982 growing season, dried at 131°F (55° C), and weighed.

Statistical analyses included a comparison of production, height, and cover on seeded plots among amendment combinations and planting dates, using factorial analysis of variance. A T-test was used to compare plant density between seeded and unseeded plots.

RESULTS AND DISCUSSION

Gypsum and sawdust were effective in increasing ($p = 0.05$) production, height, and cover of rillscale only on those spoils amended and seeded in the fall of 1981 (table 1). On spoils amended and seeded in the spring of 1982, the sawdust increased cover, but not height or production, while the gypsum had no effect on production, height, or cover. Fertilizer reduced ($p = 0.05$) height of rillscale on plots amended and seeded in the spring of 1982, and had no effect on plants within treatment plots amended and seeded in the fall of 1981 (table 1). Fertilizer, applied either in the spring or fall, did not affect production or cover of rillscale.

Although amendment effects were generally independent of one another, an interaction between fertilizer and sawdust on height of rillscale when these amendments were added in the spring, was revealed. This interaction was expressed as lower than expected height-increasing effects of sawdust when fertilizer was also added and lower height-decreasing effects of fertilizer when sawdust was also added. This interaction may have caused height means, as presented in table 1, to be somewhat biased, with the mean for height with sawdust being slightly underestimated and the mean for height with fertilizer being slightly overestimated.

Height and cover of rillscale on plots amended and seeded in the fall of 1981 were greater ($p = 0.05$) than on plots amended and seeded in the spring of 1982 (table 1). However, production did not differ between these two sets of plots. As an annual, rillscale probably initiates growth very early in the spring, before field conditions allow spring amendment and seeding. This would explain the decreased height and cover of rillscale on plots that had been tilled, amended, and seeded in the spring of 1982 as compared to the fall. Annual precipitation for 1982 was 42 percent above normal (May through August) providing inordinately favorable growing conditions for both spring and fall plantings.

[1] Personal communication with R. Sieg, American Colloid Co., Rapid City, South Dakota, Aug. 1982.

Table 1.--Production, height, and cover of rillscale during the 1982 growing season as affected by amendments of gypsum, sawdust, and fertilizer, and by season of application of these amendments.

Amendment	Production Fall	Production Spring	Height Fall	Height Spring	Cover Fall	Cover Spring
	--Pounds/Acre--		--Inches--		--Percent--	
All amendments	[1]1462 a	1096 a	3.9 a	2.0 b	42 a	26 b
Gypsum						
without	[2]955 a	1165 a	3.2 a	2.2 a	31 a	29 a
with	1813 b	972 a	4.6 b	1.9 a	53 b	23 a
Sawdust						
without	843 a	1003 a	2.9 a	1.8 a	28 a	19 a
with	1561 b	1134 a	4.9 b	2.2 a	56 b	33 b
Fertilizer						
without	1973 a	1187 a	3.6 a	2.5 b	37 a	29 a
with	1695 a	949 a	4.1 a	1.6 a	47 a	23 a

[1]Numbers in each spring-fall comparison that are followed by the same letter are not significantly different ($p = 0.05$).

[2]Numbers in a column for each amendment category that are followed by the same letter are not significantly different ($p = 0.05$).

The mid-May density of plants on seeded plots was 131 plants/ft^2 (1,323 plants/m^2) and exceeded ($p = 0.05$) density of plants on unseeded plots (59 plants/ft^2, 596 plants/m^2) on spoils amended and seeded in the fall of 1981. Seeding of amended plots in the spring of 1982 did not increase the density of plants above the density of plants on amended plots that were not seeded. Density of spring-amended plots averaged 11 plants/ft^2 (111 plants/m^2).

CONCLUSIONS

The addition of fertilizer to bentonite mine spoils was not shown to be effective, regardless of season. Additions of sawdust and gypsum in the fall were shown to be effective for improving spoils as plant growth media, primarily because of their effects on physical characteristics of the spoils. Increased production and cover resulting from the addition of sawdust or gypsum are expected to have a significant effect on spoil protection and stabilization, and on the rate of soil development over spoils.

The timing of spoils modifications is important. Fall amendments and seeding were shown to be more effective than spring amendments and seeding. Spring amendments had no effect on production, height, or cover of rillscale with two exceptions: (1) spring additions of sawdust resulted in increased cover of rillscale, and (2) spring additions of fertilizer resulted in decreased height of rillscale. Fall amendment and seeding were generally found to be more practicable than spring amendment and seeding because of more favorable weather conditions. Fall additions of gypsum and sawdust are, therefore, recommended for the improvement of bentonite mine spoils as plant growth media. When fall applications are not practicable and cover is critical, sawdust should be applied in the spring. Increased seedling density was observed when seed was added in the fall, but not when seed was added in spring. This effect is attributed to the climatic requirements of rillscale for germination and establishment. Seeding should be done in the fall where increased density of rillscale is desired.

Rillscale responded to spoils amendments and seeding with increased production, height, and density. The potential of rillscale for use as a revegetating species on bentonite mine spoils is thus supported by these results.

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This proceedings, second in a series of publications of wildland shrub symposia, brings together current knowledge of plants belonging to the chenopod family. Topics addressed by the 46 papers include distribution, systematics, genetics, ecological relationships, physiology, seed technology, animal relationships, and revegetation techniques.

KEYWORDS: Chenopodiaceae, *Atriplex*, *Ceratoides*, *Kochia*, distribution, systematics, genetics, ecology, physiology, seeds, insects, grazing use, wildlife use, revegetation, mined land reclamation

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Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)